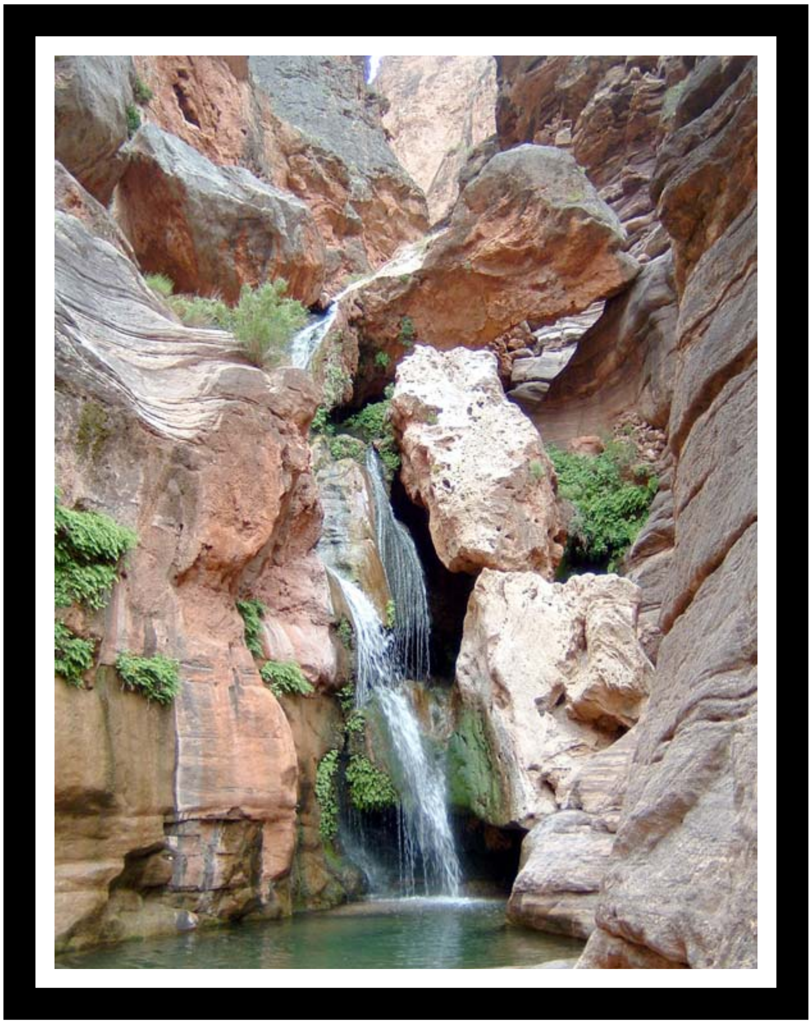
A WATER QUALITY INVESTIGATION OF SEVENTEEN GRAND CANYON TRIBUTARIES: JULY 2004 – MAY 2005



ADEQ
Arizona Department of Environmental Quality

Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Prepared by

Division of Water
Surface Water Section
Monitoring Unit
1110 W. Washington Street
Phoenix, Arizona 85007

Lin Lawson, Editor

<u>Contributors</u>

Lee Johnson
Jason Jones
Doug McCarty
Kyle Palmer
Steven Pawlowski
Sam Rector
Patti Spindler
Roland Williams

The Arizona Department of Environmental Quality shall preserve, protect and enhance the environment and public health, and shall be a leader in the development of public policy to maintain and improve the quality of Arizona's air, land and water resources.

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EXECUTIVE SUMMARY

The water quality of 17 Colorado River tributaries within Grand Canyon National Park was sampled quarterly from July 2004 through May 2005. Water sample analyses included nutrients, inorganics, suspended sediment concentration, turbidity, *Escherichia coli* bacteria, total and dissolved metals and trace metals.

The water quality of 16 of the tributaries is considered to be good with few exceedences of the state's water quality standards. An exceedence of the Human Health standard for arsenic occurred once at Crystal Creek. Selenium occurred infrequently with no exceedences of water quality standards. Trace metal sampling revealed three exceedences of the Human Health standard for lead; once at Kanab Creek and twice at the Paria River. There were no exceedences for copper and mercury. Nutrient levels at all sites were generally low except for the Paria River which had high concentrations of phosphorus and organic nitrogen. Suspended sediment fractions were related to rim origin and distance from source water. The Paria River consistently had high turbidity measurements. The presence of *E. coli* bacteria was minimal and within normal background levels at all tributaries except for the Paria River which had consistently high colony counts and exceedences of the acute and chronic *E. coli* water quality standards.

Loadings of selected parameters at all sample sites were calculated to determine loading contributions to the Colorado River. The Paria River is contributing sizable and sometimes substantial amounts of arsenic, selenium, copper, lead, mercury, nitrogen, phosphorus, total suspended sediments, and *E. coli* bacteria.

Macroinvertebrates were sampled in the spring of 2005 from 13 sites in 12 of the tributaries. However, the samples were classified as "compromised" due to natural flooding conditions at time of sampling and are considered unacceptable for 305(b)/303(d) assessments and listing purposes. Results presented in the report are for informational purposes only. Data revealed that all but one tributary had low macroinvertebrate Index of Biological Integrity scores which cannot be related to water quality but did validate flooding disturbance.

TABLE OF CONTENTS

Page
Acknowledgements ... iii
Executive Summary ... iv
Table of Contents ... 1
Tables ... 2
Figures ... 3
Appendices ... 4
Introduction ... 5
    Purpose and Scope ... 5
    Sampling Design ... 6
    Sampling sites ... 6
    Sampling Duration and Frequency ... 8
    Target analytes ... 9
Sample Methods ... 10
Water Quality of Grand Canyon Tributaries ... 11
    Water Types – Ionic Composition ... 12
    Arizona Water Quality Standards ... 15
    Ambient Surface Water Metals ... 15
        Arsenic (As) ... 15
        Selenium (Se) ... 20
        Trace Metal Sampling – Copper, Lead, and Mercury ... 22
            Copper (Cu) ... 23
            Lead (Pb) ... 24
            Mercury (Hg) ... 25
            Conclusions – Trace Metals ... 27
    Nutrients ... 29
    Suspended Sediment Concentration (SSC) ... 35
    Turbidity ... 38
    Bacteria ... 41
        Results ... 41
        Conclusions ... 42
Bioassessments and Habitat Assessments of Colorado River Tributary Streams ... 43
    Background ... 43
    Methods and Study Area ... 44
    Overall Bioassessment Results ... 45
    Geographic Analysis of Biological Results ... 49
    North and South Rim Stream Comparisons ... 50
    Other Patterns in the Data ... 51
    Habitat Results ... 51
    Conclusions ... 52
Literature Cited ... 54

LIST OF TABLES

Page

Table 1. Grand Canyon Tributary Sampling Sites 8
Table 2. Target Analytes 9
Table 3. Measured parameters and Method Reporting Limits (MRL) 11
Table 4. Arsenic concentrations at sites having values at or above the Method Reporting Limit 17
Table 5. Sample day total arsenic loadings as pounds per day 20
Table 6. Occurrence of selenium at sample sites by date 21
Table 7. Mean selenium loadings at sites having concentration values above the MRL 22
Table 8. Estimated annual dissolved mercury loading being contributed to the Colorado River 29
Table 9. Mean nitrogen and phosphorus concentrations 31
Table 10. Nutrient loadings on Grand Canyon tributaries 33
Table 11a. Typical daily TKN loadings 34
Table 11b. Typical daily total nitrite plus nitrate loadings 34
Table 11c. Typical daily total phosphorus loadings 35
Table 12. Fine and Coarse Suspended Sediment Fraction concentrations by site 36
Table 13. Daily Suspended Sediment Concentration loadings at sample sites with and without flood flows 39
Table 14. Creeks having the highest suspended sediment loadings per square mile of watershed area 39
Table 15. Bacteria samples exceeding 100 cfu/100 ml 41
Table 16. Effects of flow and rain on *E. coli* colony counts at Bright Angel Creek 42
Table 17. Macroinvertebrate Index of Biological Integrity thresholds for wadeable, perennial streams of Arizona 43
Table 18. ADEQ Macroinvertebrate sample collection history at Colorado River tributary stream sites, 1992-2006 45
Table 19. Bioassessment scores for Colorado River tributary streams sampled in May 2005 46
Table 20. Warm water macroinvertebrate metric values for Colorado River tributary streams sampled in May 2005 48

LIST OF FIGURES

Page
Figure 1. Location of monitoring sites with ADEQ site codes..7
Figure 2. Stiff diagrams of bicarbonate waters..13
Figure 3. Stiff diagrams of sulfate and mixed ionic waters 14
Figure 4. A compilation of National Park Service data on the occurrence of total arsenic in tributaries to the Colorado River in the Grand canyon, 1992-1994..19
Figure 5. Mean arsenic loadings in pounds per day...19
Figure 6. Estimated annual dissolved copper loadings for the seventeen sampled tributaries to the Colorado River...24
Figure 7. Estimated annual dissolved lead loadings for the seventeen sampled tributaries to the Colorado River...25
Figure 8. Dissolved mercury concentrations as nanograms per liter by site and date 26
Figure 9a. Dissolved mercury loadings, as pounds per sample by sample date for each tributary...28
Figure 9b. Dissolved mercury loadings, as pounds per sample by sample date for each tributary...28
Figure 9c. Dissolved mercury loadings, as pounds per sample by sample date for each tributary...29
Figure 10. Comparison of mean nutrient concentrations among sample sites 32
Figure 11. Percentages of Coarse and Fine Fractions of Suspended Sediment at Grand Canyon tributary sites 37
Figure 12. Turbidity as NTU by site and date 40
Figure 13. Comparison of 2005 and historic macroinvertebrate IBI Scores 46
Figure 14. Relative importance of 9 macroinvertebrate metrics in 13 Colorado River tributary sites sampled in May 2005..47
Figure 15. Correlation between drainage area and warm water IBI Score, May 2005 49
Figure 16. Correlation between drainage area and warm water IBI score, 1992-1997 49

APPENDICIES

Page
Appendix A: Site Codes and Sample Site Locations....................55
Appendix B: Arizona Designated Uses of Grand Canyon Sampled Streams....................56
Appendix C: Summary and Raw Data Tables of Ultra-Clean Metals Analysis for Copper (Cu), Lead (Pb) and Mercury (Hg) 57
Appendix D: *E. coli* Occurrence by Site and Date 65
Appendix E: Macroinvertebrate Taxa Collected from 12 Grand Canyon Tributaries....................67
Appendix F: Macroinvertebrate Metric and Index of Biological Integrity Scores for ADEQ/NPS samples collected 1992-2006....................74
Appendix G: Sample Site Habitat Assessment Data 76

INTRODUCTION

Purpose and Scope

The Arizona Department of Environmental Quality (ADEQ) is responsible for implementing a water quality monitoring program for rivers and streams in Arizona. Arizona Revised Statute §49-225 mandates that ADEQ conduct ongoing monitoring of the waters of the state to:

- Detect the presence of pollutants
- Determine compliance with applicable water quality standards
- Determine effectiveness of best management practices and best available demonstrated control technologies
- Evaluate the effects of pollutants on public health or the environment, and
- Determine water quality trends (A.R.S. §49-225).

The Clean Water Act (1972), its amendments, and Section 106 requires that states implement water quality monitoring programs to monitor, compile and analyze data on the quality of the waters of the United States and to support water quality assessments of surface waters required under §305(b) of the Clean Water Act. Under this Act, ADEQ must conduct a comprehensive assessment of the water quality of the state's surface waters every two years. This section of the Act requires ADEQ to categorize each surface water as to whether existing water quality is impaired or adequate to support attainment of the water body's designated uses. In some cases, there is not enough data or the data is incomplete to make a water quality assessment. ADEQ places such surface waters on a water quality monitoring planning list and targets them for follow-up monitoring to obtain the necessary data to fill the data gaps.

One of ADEQ's primary objectives in monitoring water quality in major tributaries of the Colorado River in the Grand Canyon was to obtain a sufficient amount of credible data to assess water quality for the §305(b) water quality assessment report. Water quality data obtained by the Grand Canyon water quality investigation is presented here and summarized in the 2006 Integrated Report titled: *2006 Status of Ambient Surface Water Quality in Arizona – Arizona's Integrated 305(b) Assessment and 303(d) Listing Report* (ADEQ (Draft), 2007).

The importance of the Colorado River to Arizona was a significant factor in sampling the Grand Canyon tributaries. The water from the Colorado is used extensively for agriculture, drinking water, and industrial uses and a significant portion of the water flows to Phoenix and Tucson via the Central Arizona Project Canal.

Specific objectives for ADEQ monitoring of Grand Canyon tributaries were to:

- Collect water quality data to characterize baseline water quality conditions in tributaries to the Colorado River
- Determine compliance with applicable surface water quality standards
- Obtain credible data for use in the §305(b) water quality assessment report
- Collect biological data on the attributes of the benthic macroinvertebrate communities in the tributary streams to assess their biological integrity, and
- Collect *E. coli* bacteria data to assess the microbiological water quality of tributary streams.

Sampling Design

ADEQ water quality monitoring program organizes its ambient water quality monitoring activities according to a 5-year rotating basin schedule. ADEQ has identified 10 river basins in Arizona for purposes of organizing data collection by the water quality monitoring program. ADEQ monitors water quality in rivers and streams located in two basins each water year. All 10 basins in the state are scheduled for monitoring over a 5-year cycle. In Water Year 2005, ADEQ conducted water quality monitoring in the Upper Colorado River-Grand Canyon and San Pedro River basins.

ADEQ used a targeted sampling design for this water quality investigation. It was not feasible or practical for ADEQ to use a probability-based sampling design or to randomly select sampling sites because of logistical and time constraints imposed by conducting water quality monitoring activities within the wilderness of the Grand Canyon.

Sampling Sites

ADEQ selected 17 sampling sites **(Figure 1)** on tributaries to the Colorado River in the Grand Canyon. Representative sampling sites on these tributary streams were selected using rigorous criteria.

- The tributary was reliably perennial. ADEQ did not attempt to sample springs, intermittent or ephemeral waters within the Grand Canyon.
- Sampling sites were established on reaches of tributary streams above their confluences with the Colorado River and within reasonable hiking distance from the river. In most cases, sampling sites were established within ½ mile above the confluence with the Colorado River. ADEQ did not sample springs or streams that required substantial hiking up side canyons or that were flowing only above the inner gorge of the Grand Canyon because of time constraints.
- Sampling sites were established where there was reasonable and safe access by boat from the Colorado River.
- Sites were established to address existing data gaps from previous stream monitoring. ADEQ had previously obtained water quality data on Grand Canyon tributaries as part of an intensive survey conducted as part of an ADEQ/National Park Service cooperative monitoring program in 1992, 1993, and 1994. A separate water quality investigation to conduct bioassessments in Grand Canyon tributaries was conducted in 1997.

The location of sampling sites (**Table 1)** is indicated by the alpha/numeric site code. The first two letters (CG) of the code indicates the Colorado River Basin within the Grand Canyon. The next three letters represents a code for the name of the stream and the following six digits is the channel course distance in miles from the confluence to the sample site.

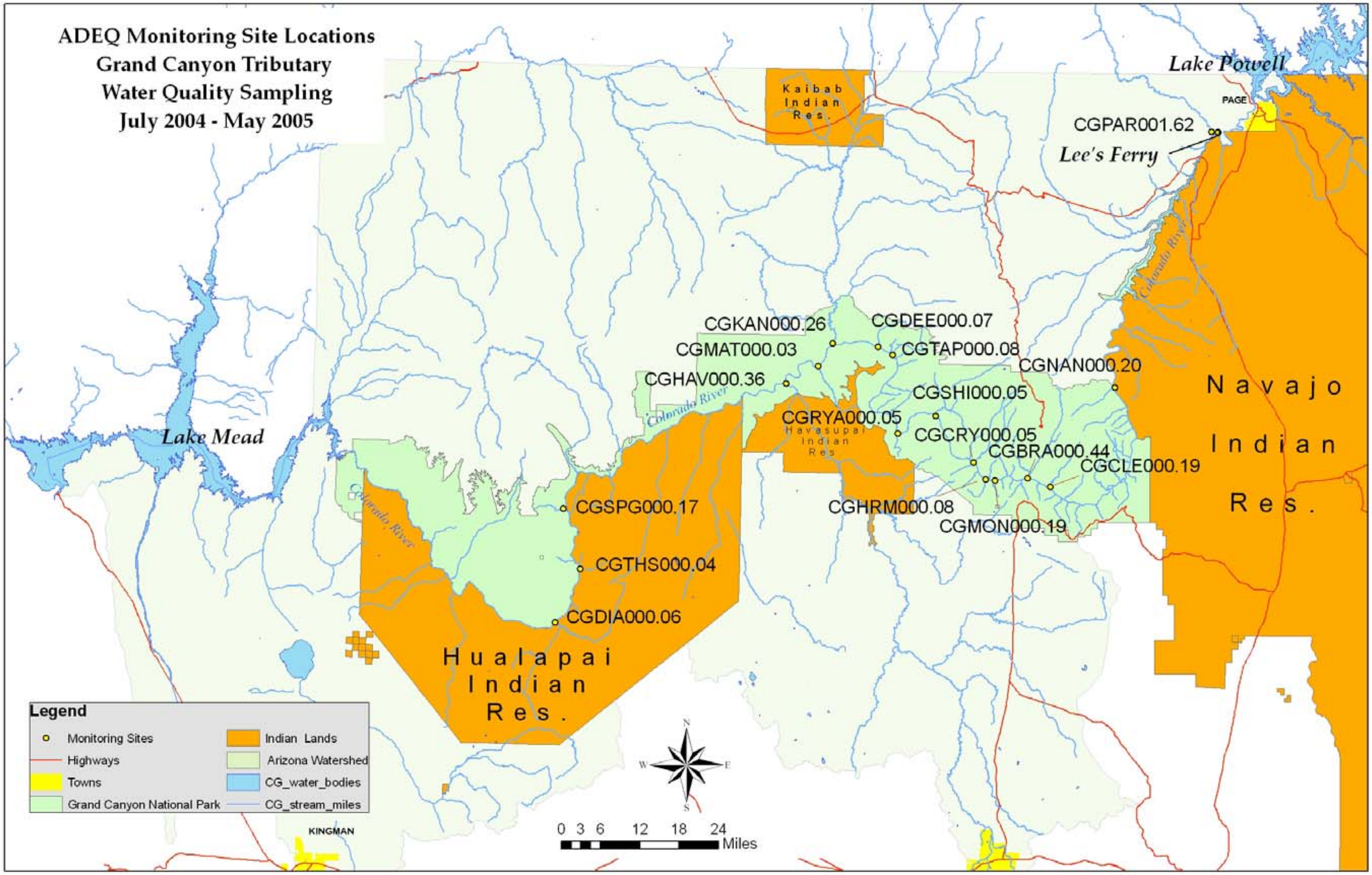


Figure 1. Location of monitoring sites with ADEQ site codes.

Table 1. Grand Canyon Tributary Sampling Sites.

Name	Sampling Site Code	Location
Paria River	CG PAR 001.62	Mile 0.1[a]
Nankoweap Creek	CG NAN 000.20	Mile 52
Clear Creek	CG CLE 000.19	Mile 84
Bright Angel Creek	CG BRA 000.44	Mile 88
Monument Creek	CG MON 000.19	Mile 93
Hermit Creek	CG HRM 000.08	Mile 95
Crystal Creek	CG CRY 000.05	Mile 98
Shinumo Creek	CG SHI 000.05	Mile 108
Royal Arch Creek	CG RYA 000.05	Mile 116
Tapeats Creek	CG TAP 000.08	Mile 134
Deer Creek	CG DEE 000.07	Mile 136
Kanab Creek	CG KAN 000.26	Mile 143
Matkatamiba Creek	CG MAT 000.03	Mile 148
Havasu Creek	CG HAV 000.36	Mile 157
Spring Canyon Creek	CG SPG 000.17	Mile 204
Three Springs Creek	CG THS 000.04	Mile 216
Diamond Creek	CGDIA 000.06	Mile 226

a – Mile "0" is located at Lee's Ferry, Arizona, which is immediately upstream of the confluence of the Paria and the Colorado Rivers.

The reference to "Mile ___" in the third column of **Table 1** is the distance in river miles from the starting point at Lee's Ferry (Mile 0), Arizona, to the stream confluence of the sampled stream. For example, the sampling site on Nankoweap Creek (CG NAN 000.20) is located 0.20 mile above the confluence with the Colorado River and 52 river miles below Lee's Ferry, Arizona. **Appendix A** presents a full description and the exact location of each site.

Sampling Duration and Frequency

ADEQ conducted water quality monitoring for this investigation in Water Year (WY) 2005, which began on July 1, 2004 and ended on June 30, 2005. ADEQ staff conducted water quality monitoring activities on four rafting trips that took place in 2004 and 2005. Each sampling trip started at Lee's Ferry and ended at Diamond Creek, a distance of 226 river miles. Each monitoring trip took approximately two weeks to complete. The 14-day river trip duration utilized motorized rafts to minimize travel time on the river.

ADEQ typically conducts quarterly monitoring of sampling sites when implementing the 5-year rotating basin monitoring program. However, because of National Park Service rules and the difficult travel conditions, ADEQ could not schedule quarterly monitoring of the tributary streams. The National Park Service prohibits the use of motorized rafts within the Grand

Canyon from September to December each year. Therefore, the monitoring schedule required a late summer sampling trip in July and August 2004, a winter trip in January 2005, and two spring trips in March and May 2005. Bioassessments were conducted at twelve of the seventeen sampling sites during the ADEQ macroinvertebrate spring index period in May, 2005.

Target Analytes

ADEQ collected data on the same core set of chemical, physical and biological water quality indicators at each sampling site and date. The core set of target analytes represents water quality information typically gathered by most state water quality monitoring programs to characterize baseline water quality conditions. The core group includes general water chemistry (inoragnics), total and dissolved metals, nutrients, and bacteria **(Table 2).**

Table 2. Target Analytes.

GROUP 1 - FIELD MEASUREMENTS		
pH	Total dissolved solids	Air temperature °C
Specific conductivity	Stream flow	Water temperature °C
Dissolved oxygen (mg/L & % Sat.)	Turbidity	

GROUP 2 - GENERAL CHEMISTRY		
pH	Sulfate, total	Bicarbonate
Specific conductivity	Fluoride, total	Carbonate
Calcium, total	Chloride, total	Alkalinity, total
Magnesium, total	Total dissolved solids	Hardness
Sodium, total	Total suspended solids	
Potassium, total	Suspended sediment concentration	

GROUP 3 - NUTRIENTS	
Nitrogen, Ammonia (NH_3-N)	Nitrogen, total $N0_2$/$N0_3$
Phosphorous, total	Nitrogen, Total Kjeldahl

GROUP 4 - DISSOLVED METALS			
Antimony	Beryllium	Copper	Mercury
Arsenic	Cadmium	Lead	Zinc

GROUP 5 - TOTAL METALS			
Antimony	Boron	Copper	Mercury
Arsenic	Cadmium	Lead	Selenium
Beryllium	Chromium	Manganese	Zinc

GROUP 6 - BACTERIA
Escherichia coli (E. coli)

GROUP 7 - BIOLOGICAL
Benthic macroinvertebrates

SAMPLE METHODS

Representative water samples, biological samples and environmental measurements were collected using methods described in *A Manual of Procedures for the Sampling of Surface Waters (Lawson, 2006)*.

A suite of field measurements were obtained at each sampling site using a Hydrolab multi-parameter probe to measure specific electrical conductance (µmhos/cm), dissolved oxygen (mg/l), percent oxygen saturation, pH (SU), water temperature (°C), and total dissolved solids (mg/l). Turbidity was measured with a portable Hach 2100P Turbidimeter. Stream velocity (ft/sec) was measured with a Marsh-McBirney flow meter and converted to discharge (cfs) from the sample site cross-section measurements.

Grab water samples were collected from the undisturbed uppermost end of a sampling reach in the main flow of water. Dissolved metal samples were field filtered. Samples were chilled until delivery to the Arizona Department of Health Services, State Laboratory in Phoenix, where the designated analyses were performed.

A two-set water sample was collected with specialized handling (USEPA Method 1669, Clean Sampling of Natural Waters for Trace Metals) and field processed. Samples were analyzed for dissolved lead, copper, and mercury at Albion Environmental, College Station, Texas. Duplicate and split samples were collected. Deviations from Method 1669 are permitted provided that reliable analyses of samples are obtained and that sample blanks are not contaminated. Four deviations were employed due to environmental, weather and water conditions: 1) a delayed filtration by a single person, 2) field blanks were not processed at every site, 3) at sites having high turbidity, the water samples were pumped through geofilters rather than the small capacity filters supplied by the vendor, and 4) a single container, shielded with a plastic envelope to prevent air contamination of water samples, was used during the entire trip for processing all water samples.

Bacteria samples were filtered and field incubated for twenty-four hours on mTEC media and field enumerated. Bacteria samples were not processed at some sites when the sample could not pass through the membrane filter due to excessive turbidity.

Macroinvertebrates were collected from a 3-minute timed kick sample with a D-frame kick net in riffles and runs. Some samples were collected during high flows although ADEQ protocols require a four week delay after high flow events. Data from these samples were not be used for bioassessments. Two sites, Tapeats Creek and Bright Angel Creek, were not sampled for macroinvertebrates due to flood flows at time of visit.

WATER QUALITY OF GRAND CANYON TRIBUTARIES

Fifty-one chemical and field parameters were measured at each site and are listed in **Table 3** together with the laboratory method and the Method Reporting Limit (MRL). Sixteen tributary sites within the Grand Canyon were sampled on a single pass through schedule. The Paria River sample site, 1.6 miles upstream from its confluence with the Colorado River and reachable by road, was sampled quarterly, but on a different sampling schedule than the other Canyon streams.

Table 3. Measured parameters and Method Reporting Limits (MRL).

Measured Parameters			Measured Parameters		
Inorganics	**Method**	**MRL**	**Metals**	**Method**	**MRL**
Alkalinity, Total (mg/L as $CaCO_3$)	SM 2320 B	2.0	*Copper, Dissolved (ug/L)*	EPA 1638	0.10
Alkalinity, Phenolphthalein (mg/L)	SM 2320 B	2.0	*Lead, Dissolved (ug/L)*	EPA 1638	0.02
Specific Conductance (µmhos/cm @ 25°C)	EPA 120.1	b	*Lead, Total (ug/L)*	EPA 200.9	10
Hardness, Total (mg/L as $CaCO_3$)	EPA 130.2	10	*Manganese, Total (ug/L)*	EPA 200.7	10
Hardness, Ca Mg Calculated (mg/L as $CaCO_3$)	a	b	*Mercury, Total (ug/L)*	SM 3112B	0.5
pH, Lab	EPA 150.1	0.1	*Mercury, Dissolved (ug/L)*	EPA 3112B	0.5
Solids, Total Dissolved (mg/L)	EPA 160.1	10	*Mercury, Dissolved (ng/L)*	EPA 1631e	0.02
Nutrients			*Selenium, Total (ug/L)*	EPA 200.9	5
Nitrite Plus Nitrate, Total (mg/L as N)	EPA 353.2	0.02	*Zinc, Total and Dissolved (ug/L)*	EPA 200.7	50
Nitrogen, Ammonia, Total (mg/L as N)	EPA 350.1	0.02	**Biological**		
Nitrogen, Kjeldahl, Total, (mg/L as N)	EPA 351.2	0.05	*E. coli (Colonies/100 ml)*	EPA 1603	2
Phosphorus, Total (mg/L as P)	EPA 365.4	0.02	**Physical Measurements**		
Major Ions			*Suspended Sediment Concentration (Gravimetric), Fine Fraction (mg/L)*	BLS 256	5.0
Bicarbonate (mg/L as HCO_3) (Anion)	a	b	*Suspended Sediment Concentration (Gravimetric), Coarse Fraction (mg/L)*	BLS 256	5.0
Carbonate Ion (mg/L as CO_3) (Anion)	a	b	*Total Suspended Solids (mg/L)*	EPA 160.2	4.0
Calcium, Total (mg/L as Ca) (Cation)	EPA 200.7	1.0	**Field Measures**		
Chloride, Total (mg/L) (Anion)	SM 4500 CL D	1.0	*Area, Cross-Section, of Stream (sq.ft.)*		b
Fluoride, Total (mg/L as F) (Anion)	SM 4500 F-C	0.05	*Depth of Stream, Mean (feet)*		b
Magnesium, Total (mg/L as Mg) (Cation)	EPA 200.7	1.0	*Flow, Stream, Instantaneous (cfs)*		b
Potassium, Total mg/L as K) (Cation)	EPA 200.7	0.5	*Flow, Rate (ft/sec.)*		b
Sodium, Total (mg/L as Na) (Cation)	EPA 200.7	1.0	*Oxygen, Dissolved (mg/L)*		b
Sulfate, Total (mg/L as SO_4) (Anion)	EPA 300.0	1.0	*Oxygen, Dissolved, Percent of Saturation*		b
Metals			*pH, Field*		b
Antimony, Total and Dissolved (ug/L)	EPA 200.9	5.0	*Specific Conductance, Field (umhos/cm @ 25°C)*		b
Arsenic, Total and Dissolved (ug/L)	EPA 200.9	10	*Stream Width (feet)*		b
Beryllium, Total and Dissolved (ug/L)	EPA 200.9	0.50	*Temperature, Water °C*		b
Boron, Total (ug/L)	EPA 200.7	100	*Temperature, Air °C*		b
Cadmium, Total and Dissolved (ug/L)	EPA 200.9	1.0	*Turbidity (NTU)*		b
Chromium, Total (ug/L)	EPA 200.7	10			
Copper, Total (ug/L)	EPA 200.7	10			

Note: MRL – Method Reporting Limit
a. A calculated value
b. Method Reporting Limit not applicable

Water Types – Ionic Composition

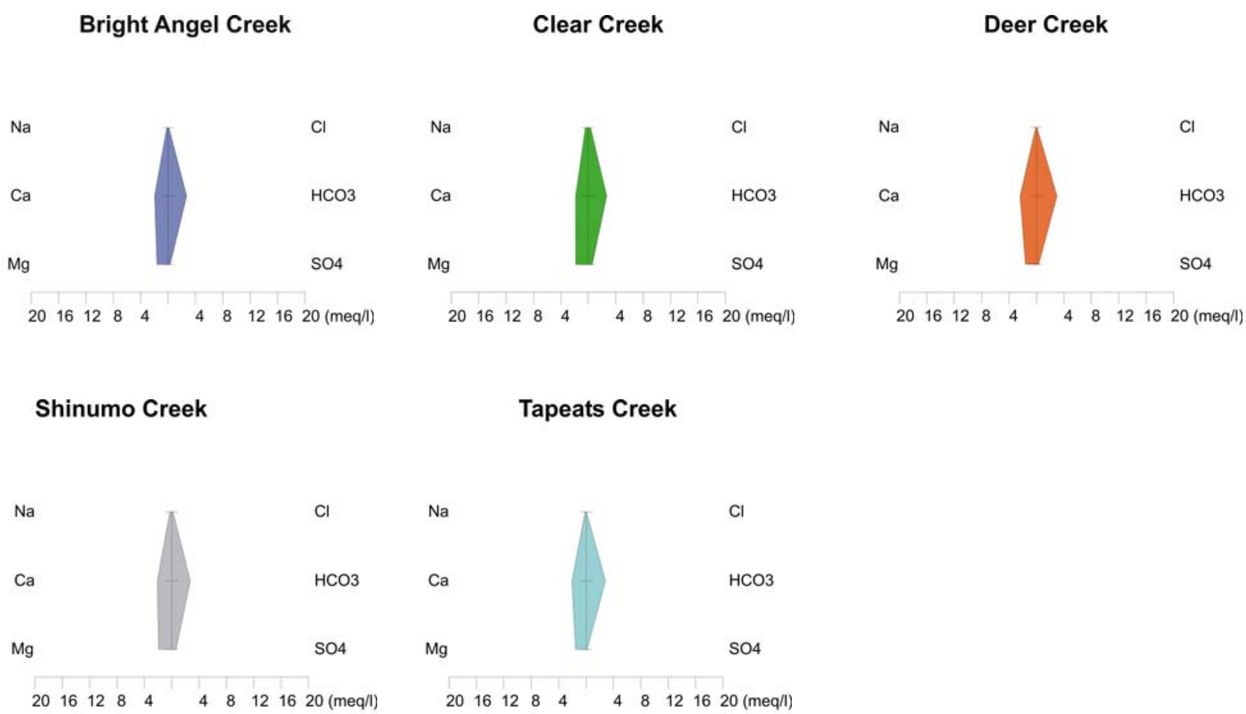
Waters can be classified by such terms as calcium-bicarbonate, magnesium-sulfate, etc. The water type represents the predominant cation and anion, expressed in milliequivalents per liter. The classifications convey general information, useful for comparison discussions, but are not precise (Hem, 1989). Four cations (sodium, potassium, calcium, magnesium) and four anions (chloride, sulfate, bicarbonate, and fluoride) were measured. Fluoride and potassium were consistently found to be minor components in the ionic balance and are not presented in the graphics. Stiff diagrams of bicarbonate and sulfate waters **(Figures 2 and 3)** were constructed on mean concentration values.

There is a variety of water types at the seventeen streams sampled. The most common water type is calcium-bicarbonate (5 streams). Three streams are calcium-sulfate and the remaining eight streams are mixtures having three or more dominant ions. There does not appear to be any commonality of water type with other data, such as rim side origin, size of watershed, or distance from source origination. The water types are likely a reflection of the particular geologic strata associated with the water and hydrologic conditions.

Relative to each other, the sum of the cations and anions, in meq/L, reveals the degree of mineralization among sampled streams. For instance, Kanab Creek (29.2 meq/L), Matkatamiba Creek (32.2), Crystal Creek (33.1) Paria River (41.1) and Monument Creek (41.7) were highly mineralized. Whereas, Tapeats Creek (6.8 meq/L), Bright Angel Creek (7.0), Deer Creek (7.5), Clear Creek (7.8) and Shinumo Creek (7.8) were the least mineralized of the seventeen streams.

Figure 2. Stiff diagrams of bicarbonate waters.

Calcium-Bicarbonate



Magnesium-Bicarbonate

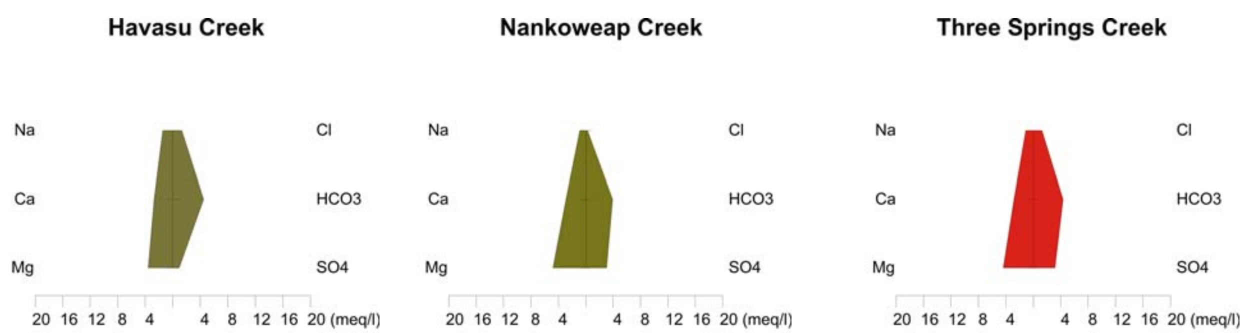
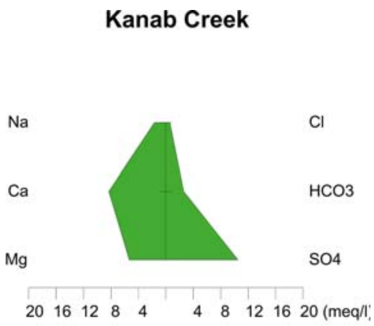
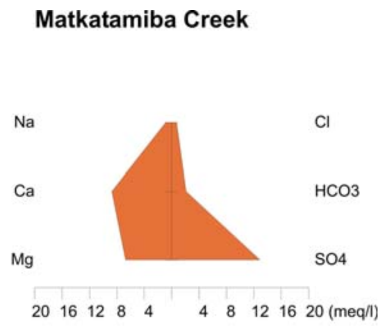
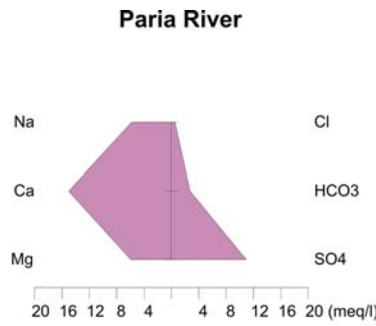


Figure 3. **Stiff diagrams of sulfate and mixed ionic waters.**

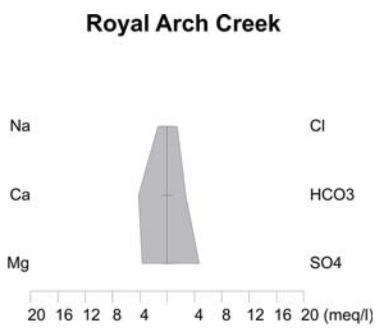
<u>Calcium-Sulfate</u>



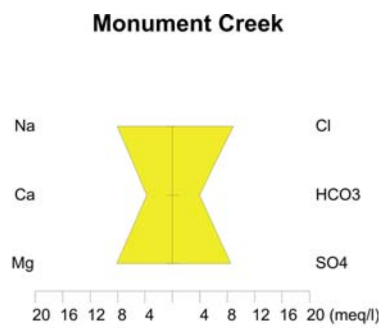




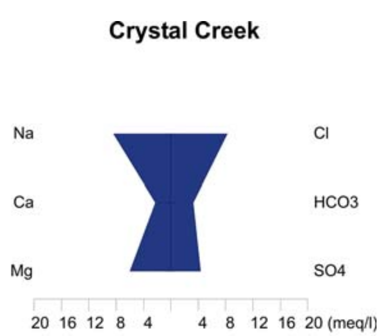
<u>Calcium-Magnesium-Sulfate</u>



<u>Sodium-Magnesium-Chloride-Sulfate</u>



<u>Sodium-Magnesium-Chloride</u>



Arizona Water Quality Standards

Aquatic and Wildlife designated uses: It is the intention of the State of Arizona that the designated uses and criteria assigned to the state's surface water will provide a level of water quality fully protective of aquatic and wildlife species dependent upon it. Water quality standards for Aquatic and Wildlife designated uses are allocated by acute and chronic conditions and are of the total and dissolved forms of a specific parameter. An acute standard would be used on the results of a single grab sample. A chronic standard is applied for compliance purposes and is determined from the geometric mean of the last four samples taken at least 24-hours apart (AAC, 2002). The applicable designated uses for Grand Canyon tributaries are acute and chronic Aquatic and Wildlife cold water (A&Wc) and warm water (A&Ww). The A&Wc designated use is applied to Nankoweap, Shinumo, and Tapeats Creeks. All other sampled streams have the A&Ww designated use applied to them.

Human Health and Agricultural designated uses: Human Health and Agricultural ambient water quality criteria are numeric values limiting the amount of chemicals present in our nation's waters. Human Health and Agricultural criteria are developed under Section 304(a) of the Clean Water Act of 1972 and Arizona Revised Statutes, Title 18, Chapter 11. The designated uses are Domestic Water Source (DWS), Fish Consumption (FC), Full Body Contact (FBC), Partial Body Contact (PBC), Agricultural Irrigation (AgI), and Agricultural Livestock watering (AgL). Kanab Creek is the only tributary with the DWS or AgL designated use. None of the sampled Colorado River tributaries are designated AgI. **Appendix B** lists the designated uses for streams sampled during this investigation.

Ambient Surface Water Metals

Eight metals were sampled at stream sites for total and dissolved fractions, while four (boron, chromium, manganese, and selenium) were analyzed for the total fraction only **(Table 3).** "Total" refers to the concentration of metals analyzed in an unfiltered sample after vigorous digestion with nitric acid to a pH of 2 or less. "Dissolved" refers to metals in the sample that will pass through a membrane filter with a pore size of 0.45 microns. After filtration, the sample is preserved with the addition of nitric acid. Dissolved metals are biologically available and some may be toxic to aquatic organisms when at elevated levels. The toxicity of some metals in the fine fraction is hardness dependent.

Arsenic (As)

Arsenic is a metal that occurs naturally in the earth's crust. It enters natural waters through the dissolution of minerals and ores. Human activities have also introduced arsenic to water from urban runoff, pesticides, fossil fuel combustion and smelting and mining wastes.

Arsenic is often found in Arizona's surface and ground waters. Odorless and virtually tasteless, arsenic concentrations are highest in areas of hydrothermal sulfide mineralization which then contribute to basin-center lake-bed deposits that may contaminate groundwater that flows through and past the clays. Many streams in the Grand Canyon receive significant contributions to flow from springs, some of which may either drain these types of alluvial deposits or may, like

Pumpkin Spring near mile 213, receive arsenic input from thermal springs. Often, the arsenic concentration in an individual stream can vary inversely with flow, with the highest concentrations seen during periods of low flow when spring inputs make up the majority of the surface flow.

While the acute toxicity of arsenic has been well documented, it is the carcinogenic potential at low concentrations that raises concern in this situation. Arsenic is categorized by the USEPA as a “class A” or demonstrated human carcinogen based on sufficient human epidemiological evidence (as opposed to animal studies). Also, increased mortality from multiple internal organ cancers (liver, kidney, lung, and bladder) and an increased incidence of skin cancer were observed in populations consuming drinking water high in inorganic arsenic” (USEPA, 1998).

Unlike the risks of toxicity posed by acute or bioaccumulable pollutants, the risk posed by carcinogens is characterized by a statistical possibility of contracting cancer from any one dose of a toxicant. This risk can be increased by either increasing the individual dose (amount of toxicant) or increasing the number of administrations of any given dose over time. In lay terms, it is like tossing a die: each time you toss it, you have a one in X chance of the die landing with a specific face up. The more times the die is tossed, the more times that one in X chance is taken.

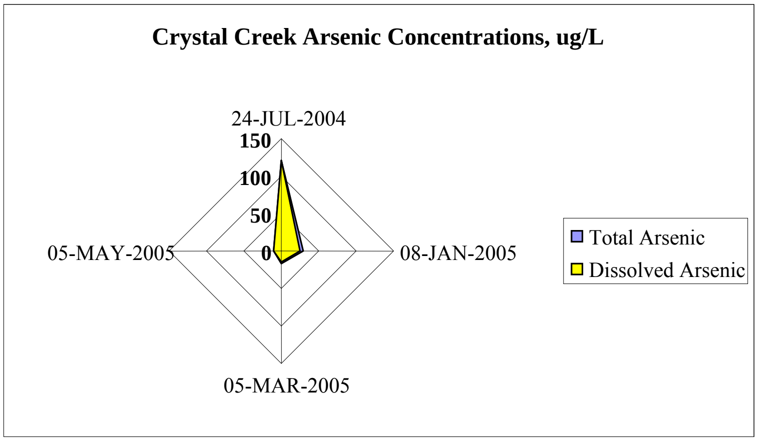
While the risk posed by the arsenic concentrations found in tributaries to the Colorado River in the Grand Canyon is statistically low, it is none-the-less a definable risk. However, this risk should not be construed as a reason to refrain from drinking water from these streams in cases of dehydration. Treatment through disinfection and filtration with most commercially available filters is not efficient in removing arsenic from natural waters. The most prudent approach is to obtain, disinfect and filter water either from the main channel of the Colorado or from tributaries with lower average arsenic concentrations.

Arsenic appeared in measurable quantities at five sites **(Table 4)**. Diamond Creek was the only site at which both the total and dissolved forms were measurable for the four sample dates. Detected amounts were slightly above the MRL at Havasu and Monument Creeks. The highest concentration was found at Crystal Creek in the July 2004 sample (120 µg/L for both total and dissolved), which exceeded the Arizona Human Health water quality standard of 50 µg/L total arsenic. Arsenic at Havasu Creek was principally in the particulate form, whereas at the other four sites the dissolved form constituted either all or the majority of detected arsenic.

Total Arsenic - Human Health Standards (µg/L)			
Domestic Water Source	Fish Consumption	Full Body Contact	Agriculture Livestock
50	1450	**50**	200

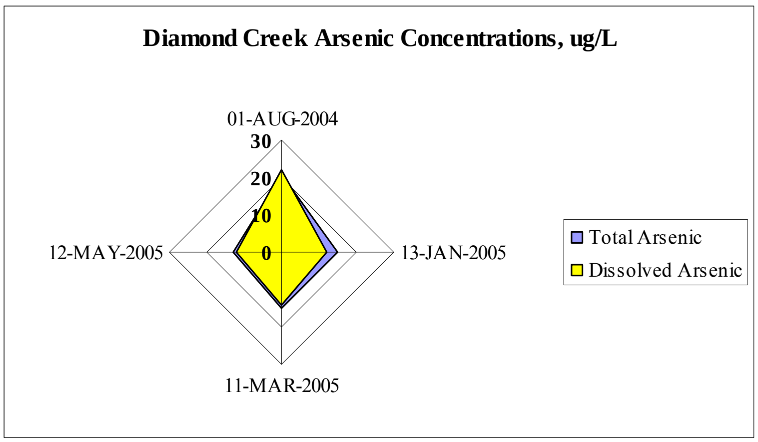
The Human Health water quality national maximum contaminant level for arsenic is 10 µg/L. Three of four samples taken from Crystal Creek exceeded that standard, one by a factor of 12.

Table 4. Arsenic concentrations at sites having values at or above the Method Reporting Limit.

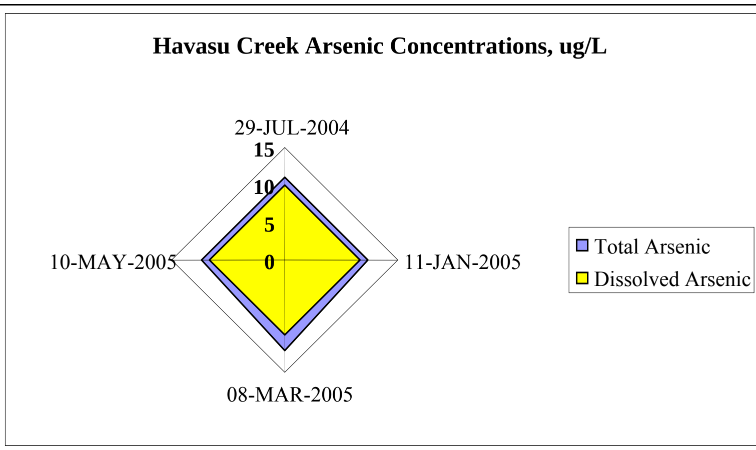


Date	Total Arsenic µg/L	Dissolved Arsenic, µg/L
24 July 2004	**120**	**120**
8 Jan. 2005	30	24
5 March 2005	16	15
5 May 2005	ND : 10	ND : 10

Highlighted red numbers indicate water quality exceedence.

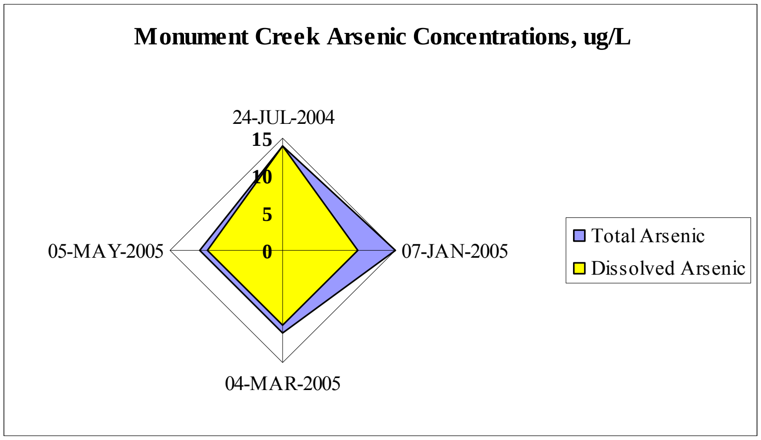


Date	Total Arsenic µg/L	Dissolved Arsenic, µg/L
1 Aug. 2004	21	22
13 Jan. 2005	15	12
11 March 2005	15	14
12 May 2005	13	12

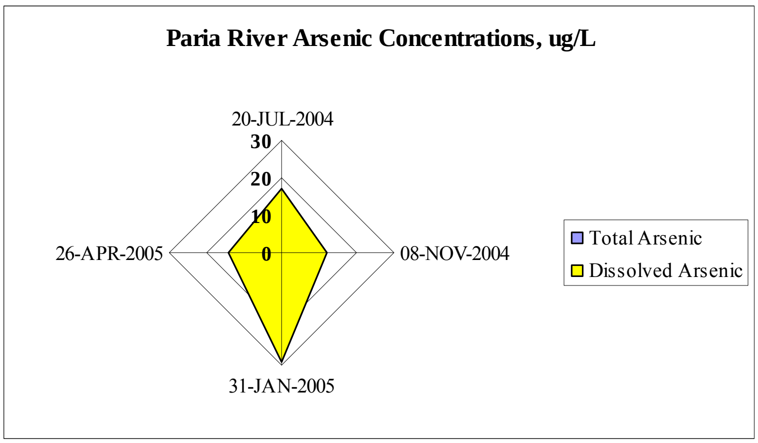


Date	Total Arsenic µg/L	Dissolved Arsenic, µg/L
29 July 2004	11	ND : 10
11 Jan. 2005	11	ND : 10
8 March 2005	12	ND : 10
10 May 2005	11	ND : 10

Table 4. Continued.



Date	Total Arsenic µg/L	Dissolved Arsenic, µg/L
24 July 2004	14	14
7 Jan. 2005	15	ND : 10
4 March 2005	11	10
5 May 2005	11	ND : 10



Date	Total Arsenic µg/L	Dissolved Arsenic, µg/L
20 July 2004	17	ND : 10
8 Nov. 2004	12	ND : 10
31 Jan 2005	29	ND : 10
26 Apr. 2005	14	ND : 10

Note: The ND (non-detect) value of 10 µg/L was used as the concentration value in the diagrams.

A review of National Park Service data stored in EPA's STORET data system found that arsenic regularly occurred at high concentrations in samples from two streams within the Canyon **(Figure 4).** Both Lava Creek (Lava Chuar) and Crystal Creek exhibited concentrations substantially above the national drinking water MCL for arsenic.

To place the concentrations of a pollutant in perspective, it is insightful to know the effective load being delivered to the receiving body of water, in this case, the Colorado River. General estimates of daily and mean annual loads of selected pollutants transported during the sampling period are used to assess relative contributions from upstream source areas. Flows were assumed to be static for the calibration period. Estimated loads were calculated for total recoverable arsenic, copper, lead, mercury, SSC, TKN, total nitrite plus nitrate, and total phosphorus. The loading formula used is:

$$\text{Load} = 3600\frac{\text{sec}}{hr} * 24\frac{hr}{day} * 62.4\frac{lbs - water}{cu.ft.} * \text{flow}\ \frac{cu.ft.}{\text{sec}} * \text{concentration in mg/L (ppm)}$$

Loadings provide a pragmatic representation of the amount of the pollutant that flows past a point at a moment in time or the estimated amount moving past that point on an annual basis. Arsenic loading at the five sites having concentrations above the MRL is shown in **Figure 5** and **Table 5**. When the concentration table **(Table 4)** is compared to the loadings table it becomes obvious that Havasu Creek and the Paria River are contributing substantial amounts of arsenic, relative to other tributaries, to the Colorado River. If the point-in-time loads are annualized, Havasu Creek is contributing approximately 1700 pounds and Paria River over 1200 pounds of total arsenic to the Colorado River, whereas Crystal Creek is contributing less than 200 pounds.

Figure 4. A compilation of National Park Service data on the occurrence of total arsenic in tributaries to the Colorado River in the Grand canyon, 1992-1994.

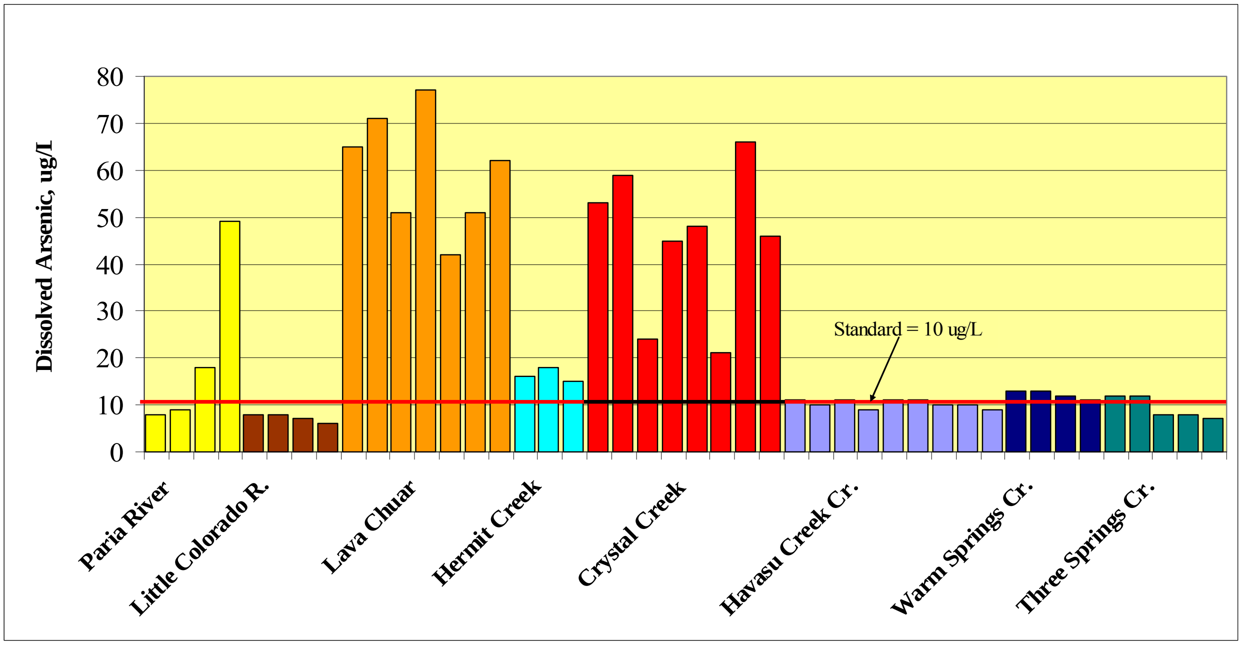


Figure 5. Mean arsenic loadings in pounds per day.

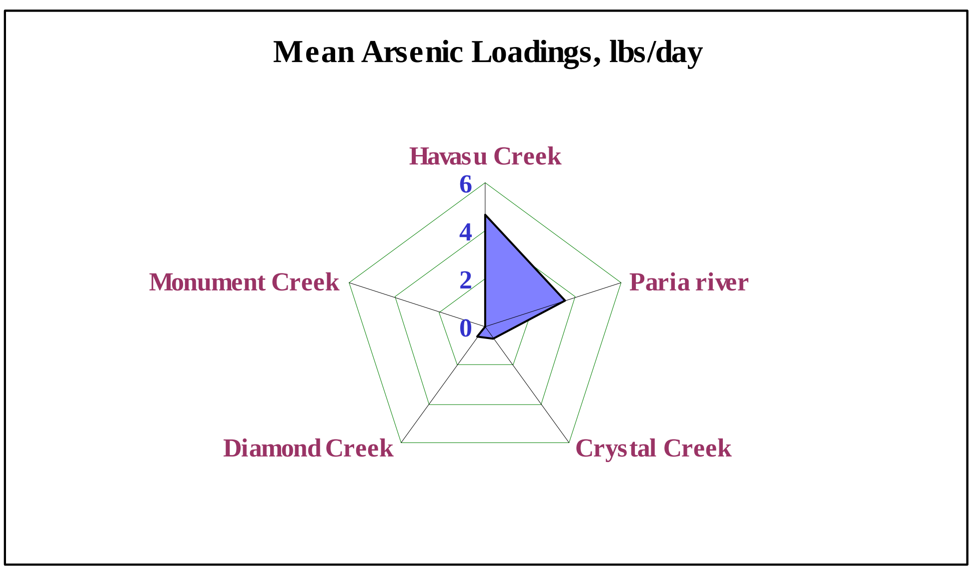
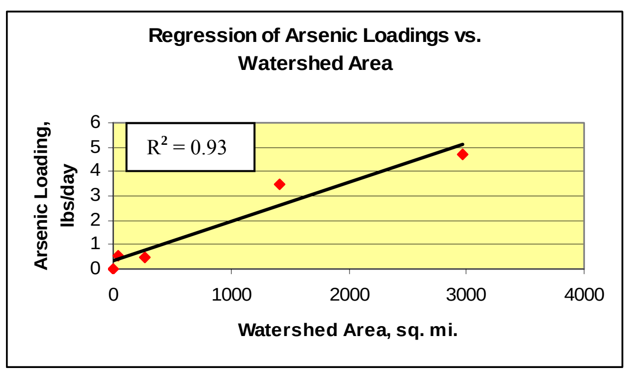


Table 5. Sample day total arsenic loadings as pounds per day.

Sample Site/ Watershed Area	Sample Date	Sample Day Loading, lbs/day	Sample Day Flow, cfs	Mean[a] Loading, lbs/day
Crystal Creek **44 sq.mi**	24 July 2004	0.03	0.04	**0.57[b]**
	8 Jan. 2005	0.39	2.4	
	5 March 2005	0.66	7.7	
	5 May 2005	<1.20*	22.34	
Diamond Creek **275 sq.mi**	1 Aug. 2004	0.09	0.8	**0.46**
	13 Jan. 2005	0.53	6.6	
	11 March 2005	0.89	11	
	12 May 2005	0.32	4.57	
Havasu Creek **2966 sq.mi**	29 July 2004	4.15	70	**4.71**
	11 Jan. 2005	4.92	83	
	8 March 2005	5.24	81	
	10 May 2005	4.51	76	
Monument Creek **0.4 sq.mi**	24 July 2004	ND	0.02	**0.02**
	7 Jan. 2005	ND	0.02	
	4 March 2005	0.04	0.73	
	5 May 2005	0.02	0.28	
Paria River **1410 sq.mi**	20 July 2004	2.93	32	**3.51**
	8 Nov. 2004	2.01	31	
	31 Jan. 2005	5.32	34	
	21 April 2005	3.77	50	

Notes:
ND represents a total arsenic concentration that was below the MRL of 10 µg/L.
a – The mean of the sample day loadings.
b - This is an estimated load. The MRL was used for the loading calculation. The actual load would have been less than the value shown. The estimated figure was retained to illustrate the relationship between flow and concentration.

When the five loadings from **Table 5** are plotted against watershed area, the regression plot indicates a good correlation and is significant at $\alpha = 0.008$; however, when all sites with non-detects are included the correlation is not significant. This may indicate that where arsenic is present in a watershed, size of watershed area and geology is the determining factor for arsenic concentration.



Selenium (Se)

Selenium occurs naturally in the environment; although being widespread it is among the rarer elements on the surface of the earth. It is released through both natural processes and human activities. It is relatively immobile in soils, but contact with oxygen will transform it into a mobile compound and easily transported in aquatic systems. In the mobile form, the chances of exposure are greatly enhanced. Selenium is an essential nutrient to the mammalian body at low levels, but is toxic at high concentrations. Humans may be exposed to selenium either through the ingestion of food or water. When selenium uptake is too high, health effects will likely arise. The seriousness of these effects depends upon the concentrations of selenium ingested and length of exposure. These health effects can be exhibited as brittle hair, deformed nails, rashes, swelling of the skin and severe body pains. Selenium poisoning may become so severe that in some cases may cause death. When animals absorb or accumulate extremely high concentrations of selenium it can cause reproductive failure and birth defects.

Selenium was present in its total form, above the MRL of 5.0 µg/L, in 16% of the water samples at seven of the seventeen sites. The A&Ww chronic standard for total selenium is 2.0 µg/L. There were not enough samples above the MRL at any of the sample sites to compute the chronic standard. Although the chronic standard does not apply to a single sample, it is useful as a benchmark comparison. All measurable occurrences of selenium were above the chronic standard in the eleven water samples **(Table 6).**

Estimated selenium loadings to the Colorado River **(Table 7)** reveal that Paria River is contributing a more substantial amount than other measured tributaries. Deer Creek contributes approximately one hundred pounds a year, while the other five streams, that had concentrations above the MRL, contribute very little over the course of a year.

Table 6. Occurrence of selenium at sample sites by date.

Site Name	Date	Total Selenium, µg/L
Deer Creek	27-Jul-2004	10
Hermit Creek	05-Mar-2005	5.4
Matkatamiba Creek	10-Jan-2005	6.1
Matkatamiba Creek	07-Mar-2005	6.7
Matkatamiba Creek	09-May-2005	5.6
Monument Creek	04-Mar-2005	6.7
Monument Creek	05-May-2005	5.5
Paria River	26-Apr-2005	14
Royal Arch Creek	25-Jul-2004	6.0
Royal Arch Creek	06-May-2005	5.1
Three Springs Creek	10-Mar-2005	6.3

Occurrence of total selenium by date and location.

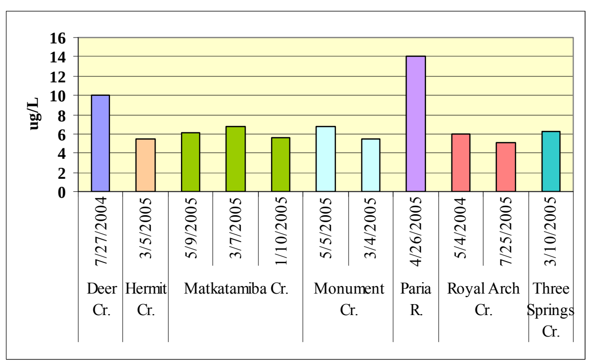


Table 7. Mean selenium loadings at sites having concentration values above the MRL.

Site Name	Mean lbs/day	Mean lbs/yr
Paria R.	3.8	1344
Deer Cr.	0.33	117
Hermit Cr.	0.05	18
Monument Cr (a).	0.02	6
Matkatamiba Cr. (b)	0.02	6
Three Springs Cr.	0.02	6
Royal Arch Cr. (a)	0.01	4

Note:
(a) Mean based on two samples
(b) Mean based on three samples

Trace Metal Sampling – Copper, Lead, and Mercury

Ultra-Clean Trace Metal Sampling, also referred to as Clean Hands Sampling, is a term commonly applied to EPA Method 1669, a protocol developed by the U. S. Environmental Protection Agency to sample metals that have been deemed toxic at low levels in ambient waters. An explanation of the ADEQ protocol is found in *A Manual of Procedures for the Sampling of Surface Waters (Lawson, 2006).* The ADEQ protocol is based on *Method 1669: Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels* (www.epa.gov). For this study, dissolved copper, lead, and mercury were the target analytes.

The Ultra-Clean protocol requires a near absolute control of the sample processing environment to prevent surface or air-borne contamination. The employment of a processing tent in the field ensured a clean environment that guarded against air-borne contamination from the strong dust laden canyon winds. A deviation from the documented protocol was required when filtering extremely turbid waters. Instead of the small 0.45 micron pore filter supplied by the contract laboratory, a larger 0.45 micron pore groundwater filter capsule was utilized. Field blanks and duplicate samples were collected at sites predetermined by the trip leader. Typically the sampling team would perform five field blanks and two field duplicates during the course of a sampling trip.

Some sample sites do not have a full compliment of four sample results for some analytes. An accident at the analyzing laboratory damaged sample bottles for 5 field grabs and 1 field blank from the May 2005 sampling run, rendering them unfit for analysis. The sample sites affected were Clear Creek, Diamond Creek, Nankoweap Creek, Shinumo Creek, and Tapeats Creek. Ultra-Clean samples were not collected from the Paria River site for 8 November 2004 and 2 May 2005. Method detection limits at the contract laboratory were: Copper 0.10 µg/L, Lead 0.02 µg/L, and Mercury 0.20 ng/L [µg/L = micrograms per liter (parts per billion) and ng/L = nanograms per liter (parts per trillion)]. A dissolved mercury sample collected on 4 March 2005 at Monument Creek produced a result of 12.7 ng/L (0.0127 µg/L), which is below A&Ww standard of 2.4 µg/L. When compared to other Grand Canyon tributary sites and years of water samples taken throughout the state, the 12.7 ng/L dissolved mercury value is unusually high. A field blank or duplicate was not taken to confirm suspected contamination, therefore the value is considered valid but questionable.

Acute and chronic Aquatic and Wildlife designated uses for copper and lead are not fixed numbers, but vary with hardness measurements. The acute standard for dissolved mercury, Aquatic and Wildlife warm and cold water, is 2.4 µg/L. The Aquatic and Wildlife warm and cold water dissolved mercury chronic standard is 0.01 µg/L (AAC, 2002). **Appendix C** presents a summary of the dissolved copper, lead, and mercury data.

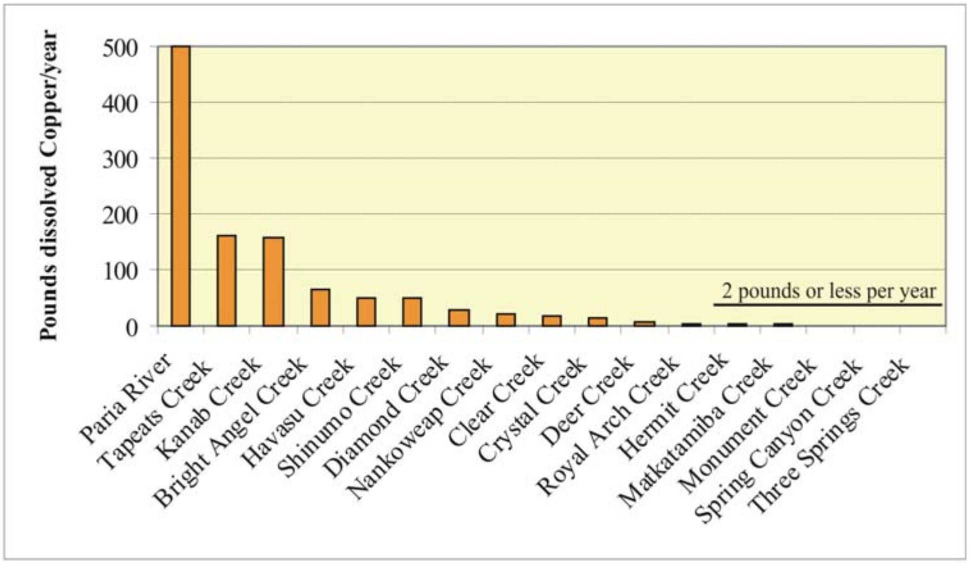
Copper (Cu)

Copper is an essential element, aiding in human, animal, and plant metabolism. However, the ingestion of excessive copper can be problematic. Ingested doses of copper, up to 100 mg, can result in severe digestive irregularities. In surface water copper can travel great distances, either suspended on sediment particles or as free ions. Levels of copper in fresh water and salt water have been found to be generally low. In the United States, studies of raw, untreated surface water have shown copper content ranging from 0.001 mg/L to 0.28 mg/L with a national mean of 0.015 mg/L.

Sixty-five samples recorded a dissolved copper value greater than the MRL. Paria River had the highest recorded concentration at 0.00318 mg/L, well below the national mean of 0.015 mg/L. The Human Health and Agricultural water quality standard is of the total form. The lowest standard is 500 µg/L for Agricultural Livestock watering and there were no exceedences of that standard. The Aquatic and Wildlife acute and chronic water quality standard for copper is of the dissolved form and there were no exceedences at any of the sample sites. The acute and chronic standard is dependent upon the hardness value at time of sampling. The most stringent standard is for chronic A&Ww and A&Wc and is 2.74 µg/L at a hardness of 65 mg/L. The lowest hardness recorded at any one sample site was 89 mg/L hardness at Clear Creek. The measured dissolved copper was 0.711 µg/L and the water quality standard for this case is 8.11 µg/L, thus there were no hardness values that could have resulted in an exceedence of the 2.74 µg/L standard. The Arizona water quality standard for total copper (total recoverable) is 1300 µg/L for DWS, FBC, and PBC, and 500 µg/L for Agricultural Livestock. There were no exceedences of these standards.

Estimated annual copper loadings, **Figure 6**, reveal that the Paria River is contributing approximately 500 pounds dissolved copper to the Colorado River. Tapeats and Kanab Creeks are discharging over a hundred pounds a year while Monument, Spring Canyon, and Three Springs Creeks are contributing negligible amounts. Streams contributing two pounds or less include Hermit Creek, Matkatamiba Creek, Monument Creek, Spring Canyon Creek, and Three Springs Creek.

Figure 6. Estimated annual dissolved copper loadings for the seventeen sampled tributaries to the Colorado River.



Lead (Pb)

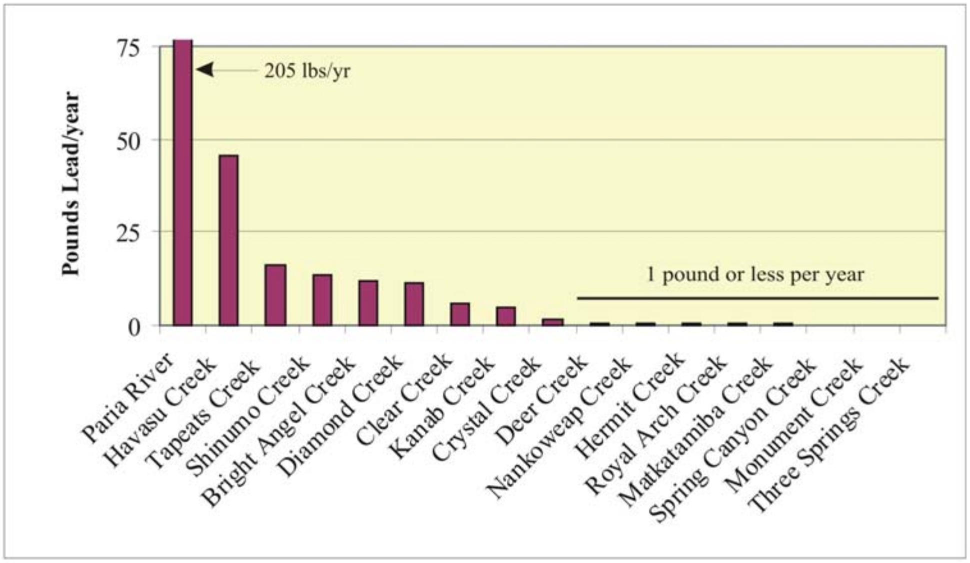
Lead is a toxic substance and has adverse effects on human and animal health. Low levels in drinking water, when continuously ingested, will cause deterioration in health. High concentrations in the body can cause death or permanent damage to the central nervous system, the brain and kidneys. Lead can bioaccumulate throughout an entire food chain.

Thirty-three samples recorded a dissolved lead value greater than the MRL. The Aquatic and Wildlife chronic and acute water quality standard for lead is of the dissolved form and there were no exceedences at any of the sample sites. The standard is dependent upon the hardness value at time of sampling. The most stringent standard is for A&Ww and A&Wc and is 0.54 µg/L at 65 mg/L hardness. There were five samples that had dissolved lead concentrations greater than 0.54 µg/L (0.00054 mg/L), but the hardness for those samples far exceeded the hardness value at the specific dissolved lead concentration that would have provided a numerical chronic or acute standard. The Human Health total lead water quality standard for DWS, FBC, and PBC is 15 µg/L. One sample at Kanab Creek and two samples at Paria River exceeded that amount. The remaining samples at those streams were below the MRL of 5.0 µg/L.

Sample Site	Sample Date	Total Lead Concentration, µg/L
Kanab Creek	28 July 2004	28
Paria River	20 July 2004	75
Paria River	31 January 2005	66

Estimated annual dissolved lead loadings **(Figure 7)** reveal that the Paria River is discharging approximately two hundred pounds to the Colorado River. This amount is more than four times that being contributed by Havasu Creek which is discharging the next highest estimated amount at forty-six pounds. Streams contributing one pound or less include Deer Creek, Hermit Creek, Matkatamiba Creek, Monument Creek, Nankoweap Creek, Royal Arch Creek, Spring Canyon Creek, and Three Springs Creek.

Figure 7. Estimated annual dissolved lead loadings for the seventeen sampled tributaries to the Colorado River.



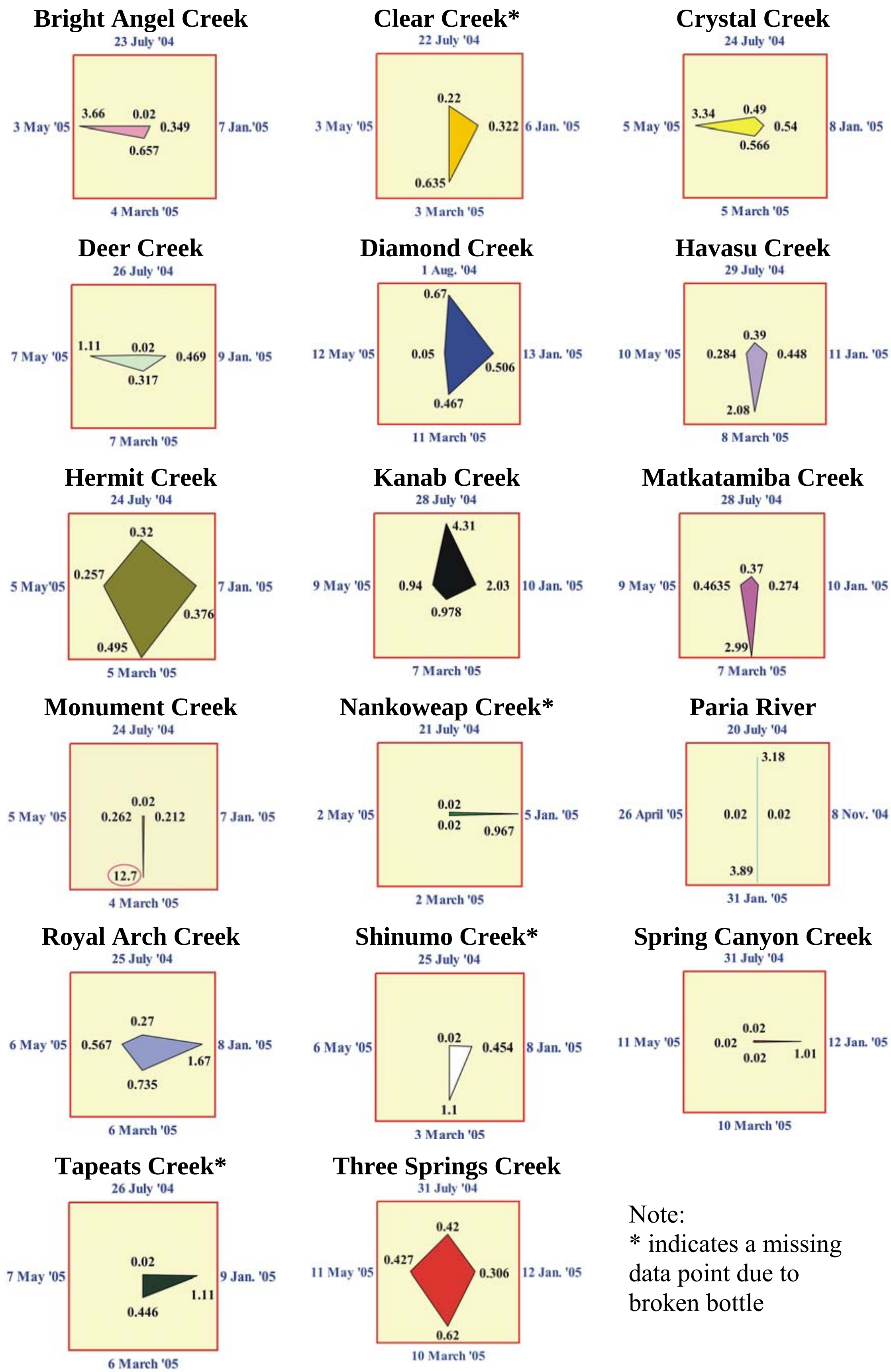
Mercury (Hg)

Mercury is a well known and naturally occurring environmental pollutant, but human activities also release significant amounts to the environment that accumulate on land surfaces, in waterbodies, and in plant and animal life. Human health concerns arise when fish and wildlife from these contaminated ecosystems are consumed by humans. High levels of mercury can lead to a wide range of physical ills, such as kidney and neurological damage, fatigue, vision problems, and tremors. Consequently, Arizona waterbodies and aquatic life tissue are regularly monitored for mercury.

Dissolved mercury occurred at each of the seventeen tributary sample sites, when measured to parts per trillion **(Figure 8).** The most stringent chronic water quality standard (0.01 µg/L or 10 ng/L) for dissolved mercury are for the A&Wc and A&Ww designated uses. There were no exceedences of that standard. One sample (12.7 ng/L; 0.0127 µg/L) at Monument Creek (March 2005) exceeded 10 ng/L; however the chronic standard does not apply to one grab sample. The Human Health Fish Consumption designated use water quality standard for total mercury is 0.6 µg/L. There were no recorded concentrations above the MRL of 0.5 µg/L and thus there were no exceedences of the total standard.

There was a small difference between north and south rims streams carrying dissolved mercury. North rim streams had an average of 1.0 ng/L whereas south rim streams had an average of 0.6 ng/L.

Figure 8. Dissolved mercury concentrations as nanograms per liter by site and date.



Note:
* indicates a missing data point due to broken bottle

Figures 9a, 9b, and 9c present dissolved mercury loadings, as pounds per sample by date for each tributary. Bright Angel Creek recorded the highest loading (3.8 lbs/day) in the March 2005 sample. Kanab Creek recorded the second highest (0.79 lbs/day) in the January 2005 sample and Paria River recorded 0.5 and 0.7 lbs/day in the July 2004 and the January 2005 samples, respectively.

Dissolved mercury loadings were annualized **(Table 8)** based on sample day mean loading. When ranked in descending order, Bright Angel Creek is estimated to be contributing approximately 500 pounds of dissolved mercury to the Colorado River. Insignificant amounts are being contributed by Matkatamiba, Spring Canyon, Hermit, and Three Springs Creeks. In total, approximately 1200 pounds of dissolved mercury is being discharged annually into the main stem river from the seventeen sampled tributaries.

Conclusions – Trace Metals

Neither acute nor chronic Aquatic and Wildlife water quality standards were exceeded for dissolved copper, lead or mercury. Three exceedences were recorded for total lead for the Human Health designated uses DWS, FBC, and PBC.

Dissolved copper was detected above the MRL in nearly every sample. Dissolved mercury was detected in measurable amounts in two-thirds of the samples, and dissolved lead in one-half of the samples.

The majority of Grand Canyon tributaries have small to medium sized watersheds that have few anthropomorphic impacts, other than recreational uses such as hiking and camping. The presence of dissolved metals in these remote hydrologic systems would appear to be related to the geological strata through which the system flows and the ability of the system to maintain that metal in a dissolved state.

Figure 9a. Dissolved mercury loadings, as pounds per sample by sample date for each tributary.

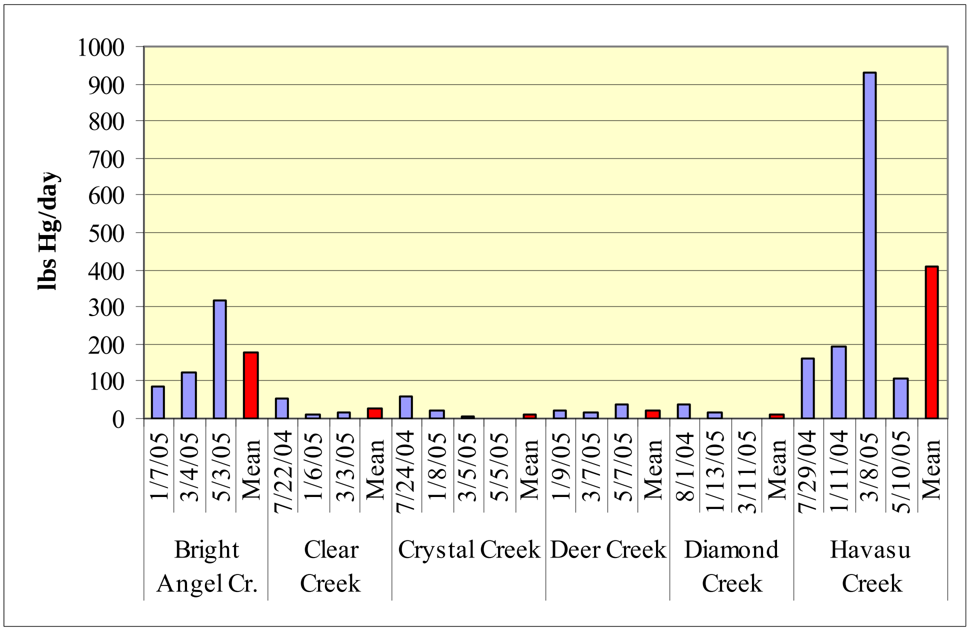


Figure 9b. Dissolved mercury loadings, as pounds per sample by sample date for each tributary.

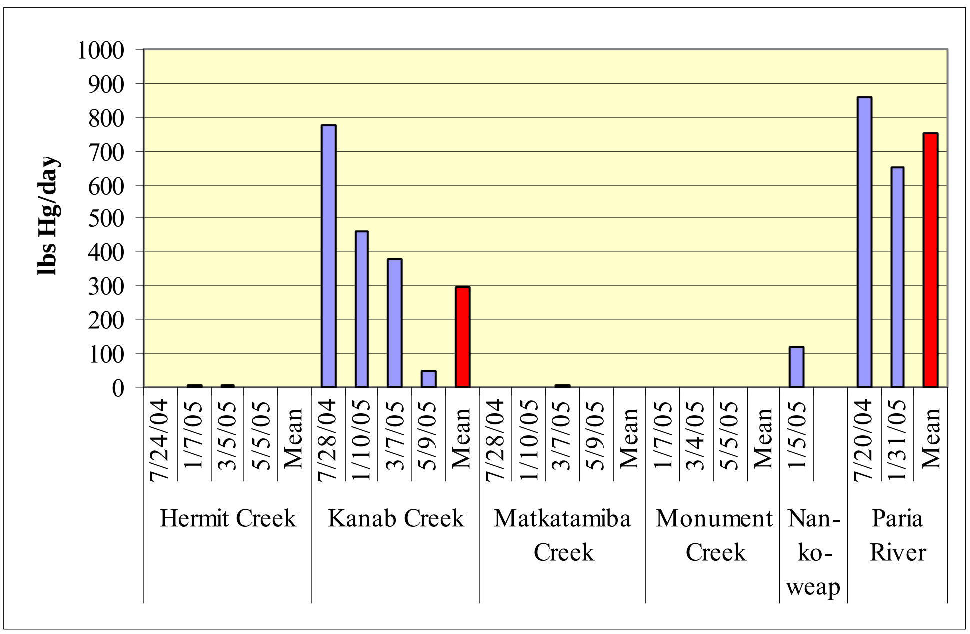


Figure 9c. Dissolved mercury loadings, as pounds per sample by sample date for each tributary.

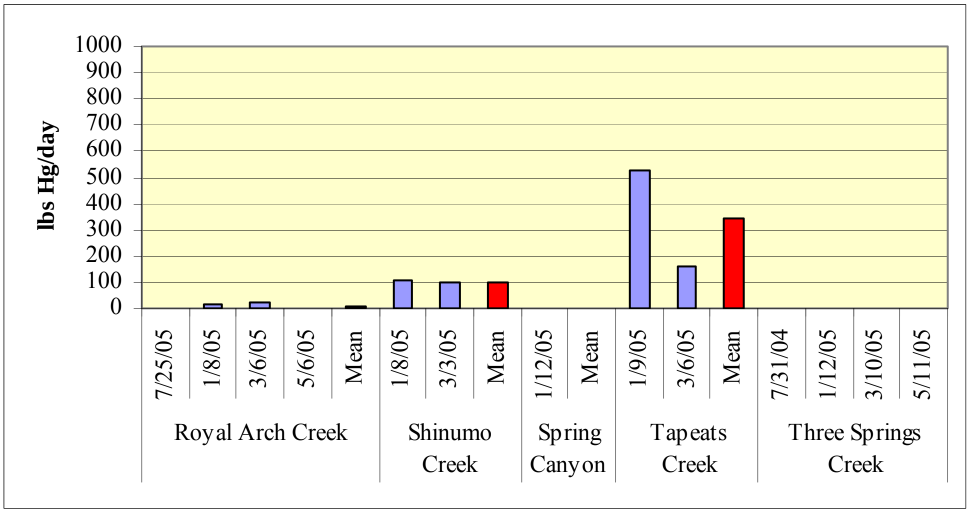


Table 8. Estimated annual dissolved mercury loading being contributed to the Colorado River.

Site Name	lbs/yr	Site Name	lbs/yr	Site Name	lbs/yr
Bright Angel Cr.	500	Crystal Creek	40	Clear Creek	3
Paria River	230	Nankoweap Creek	7	Matkatamiba Creek	1
Kanab Creek	130	Monument Creek	6	Spring Canyon Creek	1
Havasu Creek	125	Diamond Creek	6	Hermit Creek	1
Tapeats Creek	110	Royal Arch Creek	5	Three Springs Creek	<1
Shinumo Creek	55	Deer Creek	4		

Nutrients

Nutrients are chemical elements critical to the development of plant and animal life. In healthy streams, nutrients in moderate amounts are required for the growth of algae that form the base of a complex food web supporting the entire aquatic ecosystem. The most common nutrients in streams are forms of nitrogen and phosphorus.

When nutrients are abundant, algae and aquatic plants will grow excessively and multiply well beyond the amount needed to support the food web. When the excess growth dies, micro-organisms break it down, consuming dissolved oxygen from the water. Dissolved oxygen can be completely consumed in the decomposition process. The typical result is death to most if not all aquatic organisms dependant upon oxygen for life processes.

Nutrients measured were ammonia nitrogen (NH_3), nitrite (NO_2) plus nitrate (NO_3), Total Kjeldahl Nitrogen (TKN), and phosphorus. Ammonia nitrogen was detected above the MRL (0.02 mg/L) at six of the sites. Those values never exceeded 0.024 µg/L. Since this nitrogen species is a minor component of the combined nutrients it will not be further discussed. TKN is a measure of organic N and free ammonia. Since ammonia concentrations were near or below MRLs, the TKN measurements were predominantly composed of organic N. **Table 9** and **Figure 10** presents a comparison of mean concentrations of TKN, NO_2+ NO_3, and phosphorus.

Configurations of minimal phosphorus **(Figure 10)** and TKN as compared to greater amounts of NO_2+ NO_3 are the most common configurations among sites, with the exceptions of Clear Creek, Shinumo Creek, and Paria River. The two creeks had higher concentrations of TKN than NO_2+N. There is a significant difference between Paria River and all the creek sample sites. This river site had approximately four times the amount of phosphorus as the other sites and considerable higher TKN and NO_2+ NO_3 than most of the creeks. It is suspected that upstream agricultural sources, and possibly recreation, are responsible for the higher concentrations since phosphorus is the limiting nutrient in unimpaired Arizona surface waters. There are no nutrient water quality standards that apply to any of the sampled Grand Canyon tributary streams and thus compliance of water quality standards is not an issue.

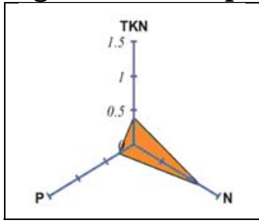
Table 10 presents nutrient loadings with (n=4) and without flood flows (n=3). The n=3 loading represents the most likely daily and annual loading to the Colorado River while the n=4 loading likely represents a maximum loading over a short period of time. **Tables 11a, 11b, and 11c** present a ranking of sites based on the particular nutrient. The relative high nutrient concentrations appear to be a function of large watershed size as shown in the three tables. The accompanying chart beside the nutrient loading table presents the relative position of a sample site to the other tributaries. Note the striking difference between the Paria River and all other sites on the tables and charts.

Table 9. Mean nitrogen and phosphorus concentrations.

Site Name	Total Kjeldahl Nitrogen mg/L as N	Total Nitrite plus Nitrate mg/L as N	Total Phosphorus mg/L as P
Bright Angel Creek	0.08[a]	0.12	0.05[a]
Clear Creek	0.27[a]	0.21[a]	0.07
Crystal Creek	0.18	0.43[a]	0.02[c]
Deer Creek	0.11[a]	0.26	0.03[a]
Diamond Creek	0.24	1.54	0.07[b]
Havasu Creek	0.11[a]	0.24	0.03[b]
Hermit Creek	0.11[a]	0.62	0.02[c]
Kanab Creek	0.39	1.20	0.27[a]
Matkatamiba Creek	0.14	0.94	0.03[b]
Monument Creek	0.11[a]	**2.83**	0.03[b]
Nankoweap Creek	0.11[d]	0.16[a]	0.05[b]
Paria River	**0.48[d]**	0.88	**3.45[d]**
Royal Arch Creek	0.16	0.93	0.05[a]
Shinumo Creek	0.11	0.05[a]	0.07[b]
Spring Canyon Creek	0.15[a]	1.06	0.02
Tapeats Creek	0.10[b]	0.13	0.05
Three Springs Creek	0.22	**2.71**	0.03[b]

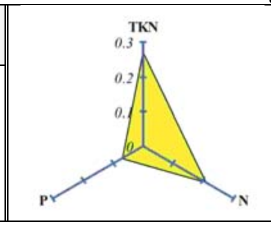
Notes:
a - one of 4 samples was at the Method Reporting Limit
b - two of 4 samples were at the Method Reporting Limit
c - three of 4 samples were at the Method Reporting Limit
d - one of the four sample analyses was performed past the holding time.
Red highlighted values indicate high or exceptionally high measured concentrations compared to other sites
Total Kjeldahl Nitrogen Method Reporting Limit was 0.05 mg/L
Total Nitrite plus Nitrate Method Reporting Limit was 0.02 mg/L
Total Phosphorus Method Reporting Limit was 0.02 mg/L
All samples at all sample sites for ammonia nitrogen as N were either at or near the Method Reporting Limit of 0.02 mg/L and therefore are not tabled.

Figure 10. Comparison of mean nutrient concentrations among sample sites.



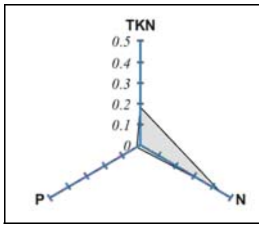
Bright Angel Creek

TKN = 0.08 mg/L
Nitrite+Nitrate = 0.12 mg/L
Phosphorus = 0.05 mg/L



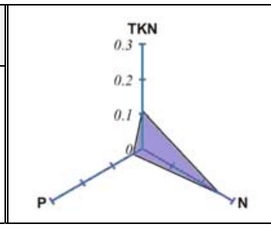
Clear Creek

TKN = 0.27 mg/L
Nitrite+Nitrate = 0.21 mg/L
Phosphorus = 0.07 mg/L



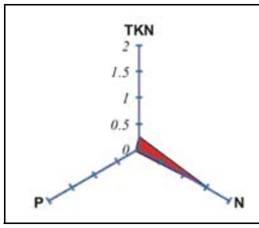
Crystal Creek

TKN = 0.18 mg/L
Nitrite+Nitrate = 0.43 mg/L
Phosphorus = 0.02 mg/L



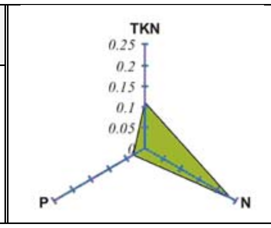
Deer Creek

TKN = 0.11 mg/L
Nitrite+Nitrate = 0.26 mg/L
Phosphorus = 0.03 mg/L



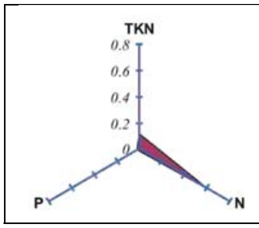
Diamond Creek

TKN = 0.24 mg/L
Nitrite+Nitrate = 1.54 mg/L
Phosphorus = 0.07 mg/L



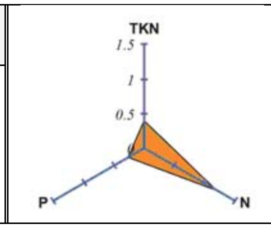
Havasu Creek

TKN = 0.11 mg/L
Nitrite+Nitrate = 0.24 mg/L
Phosphorus = 0.03 mg/L



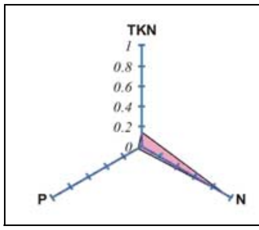
Hermit Creek

TKN = 0.11 mg/L
Nitrite+Nitrate = 0.62 mg/L
Phosphorus = 0.02 mg/L



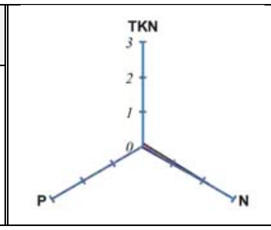
Kanab Creek

TKN = 0.39 mg/L
Nitrite+Nitrate = 1.20 mg/L
Phosphorus = 0.27 mg/L



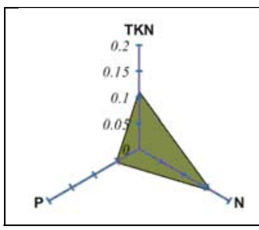
Matkatamiba Creek

TKN = 0.14 mg/L
Nitrite+Nitrate = 0.94mg/L
Phosphorus = 0.03 mg/L



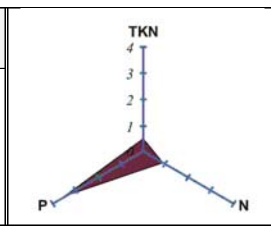
Monument Creek

TKN = 0.11 mg/L
Nitrite+Nitrate = 2.83 mg/L
Phosphorus = 0.03 mg/L



Nankoweap Creek

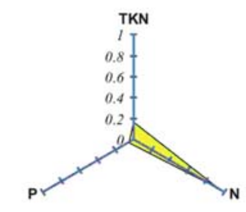
TKN = 0.11 mg/L
Nitrite+Nitrate = 0.16 mg/L
Phosphorus = 0.05 mg/L



Paria River

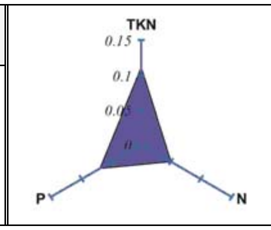
TKN = 0.48 mg/L
Nitrite+Nitrate = 0.88 mg/L
Phosphorus = 3.45 mg/L

Figure 10. Continued.



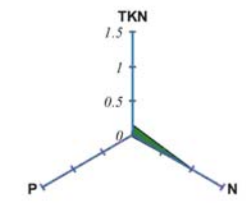
Royal Arch Creek

TKN = 0.16 mg/L
Nitrite+Nitrate = 0.93 mg/L
Phosphorus = 0.05 mg/L



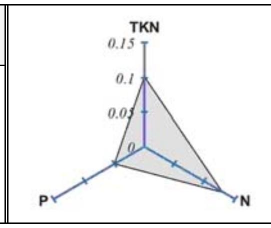
Shinumo Creek

TKN = 0.11 mg/L
Nitrite+Nitrate = 0.05 mg/L
Phosphorus = 0.07 mg/L



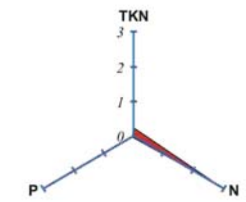
Spring Canyon Creek

TKN = 0.15 mg/L
Nitrite+Nitrate = 1.06 mg/L
Phosphorus = 0.02 mg/L



Tapeats Creek

TKN = 0.10 mg/L
Nitrite+Nitrate = 0.13 mg/L
Phosphorus = 0.05 mg/L



Three Springs Creek

TKN = 0.22 mg/L
Nitrite+Nitrate = 2.71 mg/L
Phosphorus = 0.03 mg/L

Note:
1. Axis scales are proportional to the maximum values and are not consistent among diagrams.
2. "N" represents nitrite plus nitrate.

Table 10. Nutrient loadings on Grand Canyon tributaries.

Site Name	TKN lbs/day		Nitrite + Nitrate lbs/day		Total Phosphorus lbs/day	
	n=4	n=3[a]	n=4	n=3[a]	n=4	n=3[a]
Bright Angel Creek	40	11	40	21	26	7
Clear Creek	57	1	8	7	13	<1
Crystal Creek	8	3	13	16	1	<1
Deer Creek	7	4	13	13	2	1
Diamond Creek	8	4	69	24	2	2
Havasu Creek	45	b	99	b	12	b
Hermit Creek	1	1	5	3	<1	<1
Kanab Creek	61	68	329	417	25	19
Matkatamiba Creek	<1	<1	2	<1	<1	<1
Monument Creek	<1	<1	4	2	<1	<1
Nankoweap Creek	6	4	14	13	2	2
Paria River	90	**96**	**1758**	**154**	**769**	**37**
Royal Arch Creek	2	<1	9	4	1	<1
Shinumo Creek	37	15	13	9	38	5
Spring Canyon Creek	<1	b	3	b	<1	b
Tapeats Creek	**187**	29	136	53	85	17
Three Springs Creek	<1	<1	10	5	<1	<1

Note:
(a) Loadings calculated with n=3 represent average loadings closer to actual daily values when high flow events are removed.
(b) Flood flows absent and the measured flows were consistent for the four sample dates.
The MRL, 0.05 mg/L for TKN and 0.02 mg/L for nitrite plus nitrate and phosphorus, was used in the calculations as the concentration value.
Red highlighted values indicate the highest estimated loading compared to other sites.

Table 11a. Typical daily TKN loadings.

Rank	Sample Site/Watershed Area	lbs/day
1	**Paria River**, 1410 sq. mi.	**96**
2	**Kanab Creek**, 2311 sq.mi.	**68**
3	**Havasu Creek**, 2966 sq.mi.	**45**
4	**Tapeats Creek**, 84 sq.mi.	**29**
5	**Shinumo Creek**, 86 sq.mi.	**15**
6	**Bright Angel Creek**, 100 sq.mi.	**11**
7	**Diamond Creek**, 275 sq.mi.	**4**
8	**Deer Creek**,17 sq.mi.	**4**
9	**Nankoweap Creek**, 33 sq.mi.	**4**
10	**Crystal Creek**, 44 sq.mi.	**3**
11	**Clear Creek,** 36 sq.mi.	**1**
12	**Hermit Creek**, 12 sq.mi	**1**
13	**Royal Arch Creek**, 15 sq.mi.	**<1**
14	**Spring Canyon Creek**, 22 sq.mi.	**<1**
15	**Three Springs Creek**, 17 sq.mi.	**<1**
16	**Matkatamiba Creek**, 33 sq.mi.	**<1**
17	**Monument Creek**, .4 sq.mi.	**<1**

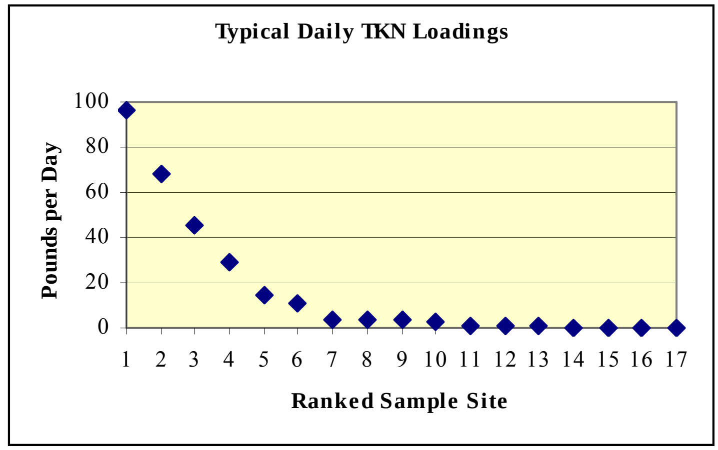


Table 11b. Typical daily total nitrite plus nitrate loadings.

Rank	Sample Site/Watershed Area	lbs/day
1	**Kanab Creek**, 2311 sq.mi.	**417**
2	**Paria River**, 1410 sq. mi.	**154**
3	**Havasu Creek**, 2966 sq.mi.	**99**
4	**Tapeats Creek**, 84 sq.mi	**53**
5	**Bright Angel Creek**, 100 sq.mi	**40**
6	**Diamond Creek**, 275 sq.mi.	**24**
7	**Crystal Creek**, 44 sq.mi	**16**
8	**Nankoweap Creek**, 33 sq.mi	**13**
9	**Deer Creek**,17 sq.mi	**13**
10	**Shinumo Creek**, 86 sq.mi.	**9**
11	**Clear Creek**, 36 sq.mi	**7**
12	**Hermit Creek**, 12 sq.mi	**5**
13	**Three Springs Creek**, 17 sq.mi	**5**
14	**Royal Arch Creek**, 15 sq.mi	**4**
15	**Spring Canyon Creek**, 22 sq.mi	**3**
16	**Monument Creek**, .4 sq.mi	**2**
17	**Matkatamiba Creek**, 33 sq.mi	**<1**

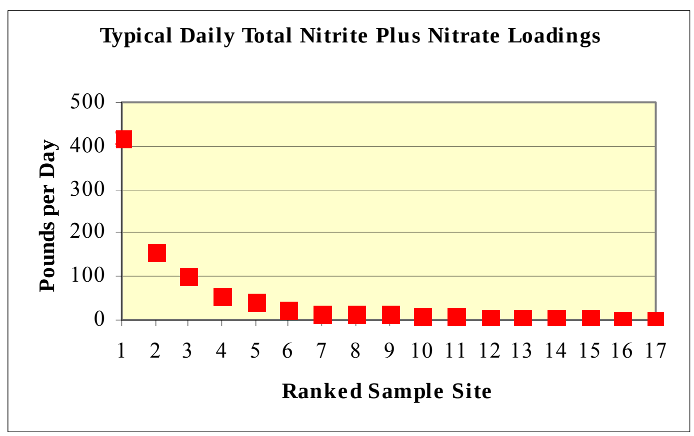
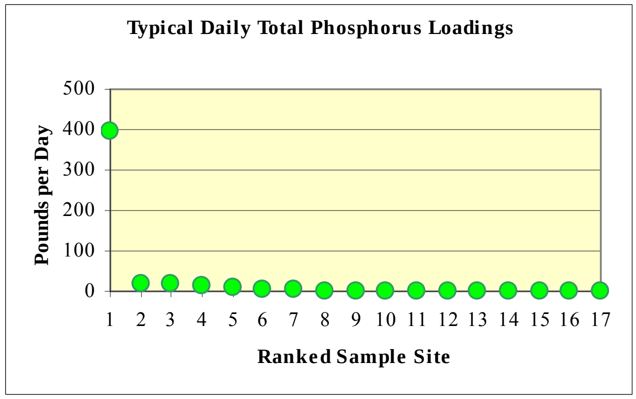


Table 11c. Typical daily total phosphorus loadings.

Rank	Sample Site/Watershed Area	lbs/day
1	**Paria River**, 1410 sq. mi.	**397**
2	**Kanab Creek**, 2311 sq.mi.	**19**
3	**Tapeats Creek**, 84 sq.mi	**17**
4	**Havasu Creek**, 2966 sq.mi.	**12**
5	**Bright Angel Creek**, 100 sq.mi	**7**
6	**Shinumo Creek**, 86 sq.mi.	**5**
7	**Diamond Creek**, 275 sq.mi.	**2**
8	**Nankoweap Creek**, 33 sq.mi	**2**
9	**Deer Creek**,17 sq.mi	**1**
10	**Clear Creek**, 36 sq.mi	**<1**
11	**Crystal Creek**, 44 sq.mi	**<1**
12	**Hermit Creek**, 12 sq.mi	**<1**
13	**Royal Arch Creek**, 15 sq.mi	**<1**
14	**Spring Canyon Creek**, 22 sq.mi	**<1**
15	**Matkatamiba Creek**, 33 sq.mi	**<1**
16	**Three Springs Creek**, 17 sq.mi	**<1**
17	**Monument Creek**, .4 sq.mi	**<1**



Suspended Sediment Concentration (SSC)

Sediments as bed load and suspended particles in the water column play a significant role in the ecology and morphology of stream channels. Sediments may have either a positive or negative influence on the channel. Most undisturbed watersheds have balance between flows and sediment transport. Unregulated streams are dynamic and reshape themselves continually. Portions of the sediment load are deposited in the channel, forming bars and riffles, and on the floodplain. These deposits may be either of short or long duration. Streams carrying high sediment loads may likely have an imbalance in the flow and sediment load. The disparity may be the result of anthropomorphic manipulations of the watershed environment or of natural conditions; e.g., a high gradient, presence of erodible soils, deserts, or lightly vegetated landscapes. When streams have an imbalance between flow and sediment load, sediments fill lakes and reservoirs and are one of the most important environmental problems throughout the world. Sediment is a important water quality problem in Arizona streams (ADEQ, 2004). Besides filling lakes and reservoirs, SSC also has an adverse effect on the biological life of aquatic organisms and it affects the water quality of drinking, recreational and industrial water. SSC can serve as a carrier and storage agent of many kinds of pollutants such as phosphorus, nitrogen, and a variety of agricultural chemicals.

Total SSC is composed of two fractions: fine and coarse. Fine Fraction consists of particles less than 62 microns. Paria River is the largest contributor of fine and coarse particles being discharged into the Colorado River **(Table 12).** The greatest amount of fine particles was 20,000 mg/L in the July 2005 sample and 7,200 mg/L of the coarse fraction in the July 2004 sample. Kanab Creek had one fine fraction sample (July 2004) of 1,400 mg/L, which was the second largest amount of the remaining fifteen sample sites. Coarse fraction samples for all streams except Paria River were below 350 mg/L. **Figure 11** illustrates the different amounts of the two fractions carried by each stream as percentage of total SSC.

There is a good relationship between the lowest and highest fine fraction SSC concentrations and rim side origin. Six of the south rim side streams had the lowest fine fraction SSC concentrations while seven of the north rim side streams had the highest concentrations. The lowest total SSC concentrations were samples taken near a spring source. The relationship of flow to total SSC is strongest at Paria River, Bright, Clear, Crystal, Deer, Shinumo, and Tapeats Creeks.

When concentrations are converted to sample day loadings, Paria River is carrying approximately 1,100 tons a day or 392,000 tons a year total SSC. The majority of the streams sampled, however, carry very little suspended sediment. **Table 13** reveals that when flood flows are removed from the loading calculations, all but Paria River, Tapeats Creek, Deer Creek, Nankoweap Creek and Clear Creek carry, on the average, one ton or less total SSC per day.

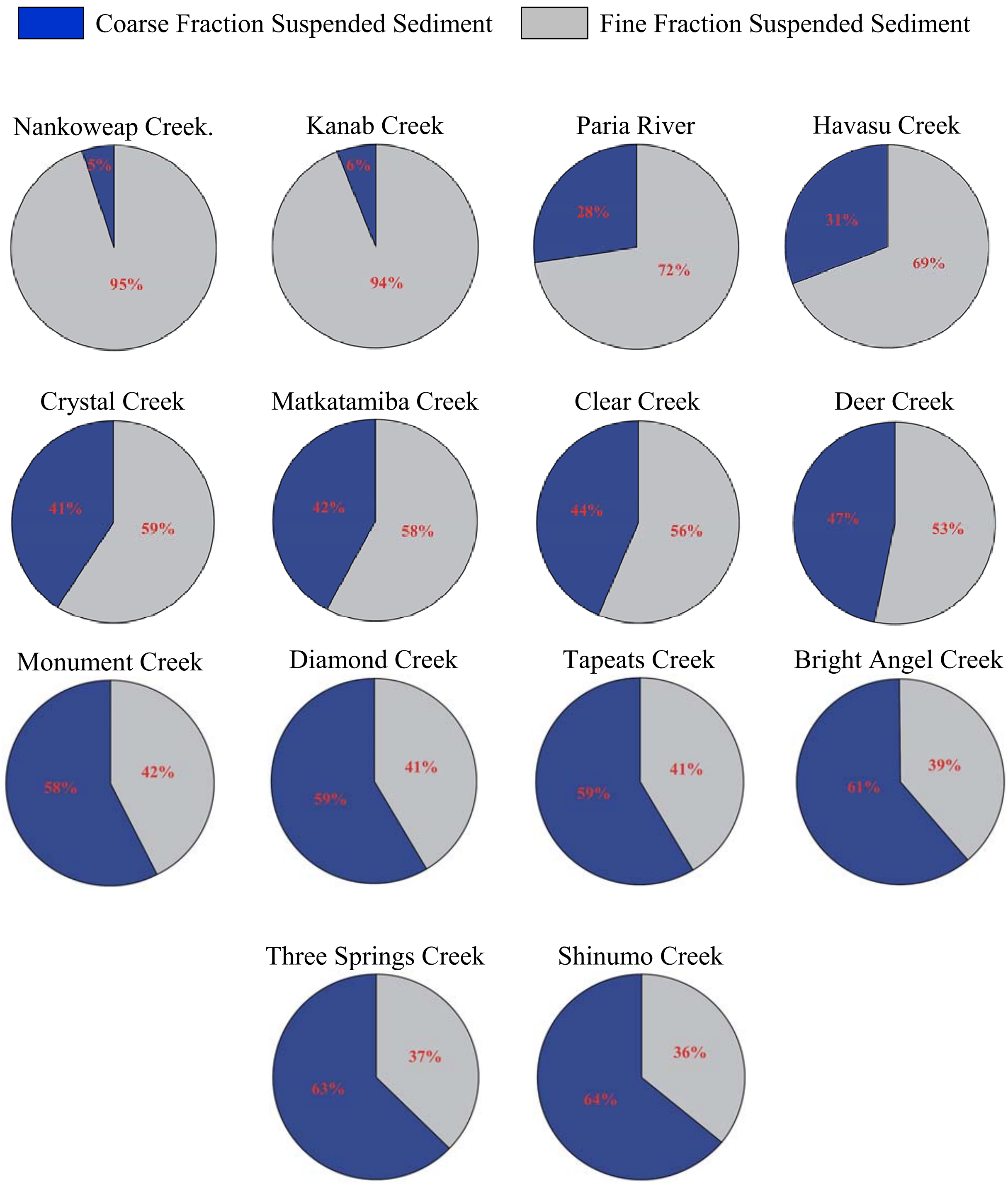
Table 12. Fine and Coarse Suspended Sediment Fraction concentrations by site.

Site Name	Fine Fraction, mg/L				Coarse Fraction, mg/L			
	July '04	Jan. '05	Mar. '05	July '05	July '04	Jan. '05	Mar. '05	July '05
Bright Angel Cr.	ND	11	ND	58	ND	ND	ND	110
Clear Creek	ND	9.4	ND	220	ND	ND	ND	170
Crystal Creek	ND	ND	ND	14	ND	ND	ND	ND
Deer Creek	ND	ND	ND	14	ND	9	ND	6.6
Diamond Creek	ND	170	6.3	ND	ND	240	14	6.2
Havasu Creek	29	ND	ND	ND	ND	ND	ND	ND
Hermit Creek	ND	ND	ND	ND	ND	ND	ND	ND
Kanab Creek	1400	29	150	24	84	6.2	ND	10
Matkatamiba Creek	ND	27	8.4	8.9	ND	11	ND	15
Monument Creek	ND	55	ND	ND	ND	80	ND	ND
Nankoweap Creek	ND	900	ND	ND	ND	32	ND	5.5
Paria River (a)	4400	3600	1200	20000	7200	3000	52	840
Royal Arch Creek	ND	ND	ND	ND	ND	ND	ND	ND
Shinumo Creek	17	ND	ND	170	12	ND	ND	330
Spring Canyon Creek	ND	ND	ND	ND	ND	ND	ND	ND
Tapeats Creek	ND	ND	ND	43	ND	ND	ND	67
Three Springs Creek	ND	ND	ND	ND	ND	18	ND	5.6

Note:
The ND MRL for SSC is 5.0 mg/L.
(a) Sample dates were July and November 2004 and January and April 2005.

The A&Wc and A&Ww chronic numeric water quality standard for total suspended sediment concentration is 80 mg/L (AAC, 2002). This standard is the geometric mean of the most recent four samples and "applies to a surface water that is at or near base flow and does not apply to a surface water during or soon after a precipitation event." There was one exceedence of this standard during the study period. The geometric mean of the four Paria River samples is 6685 mg/L.

Figure 11. Percentages of Coarse and Fine Fractions of Suspended Sediment at Grand Canyon tributary sites.



Note: Sample sites that did not have both the concentrations of the Fine Fraction and the Coarse Fraction above the MRL of 5.0 mg/L are not represented (Crystal, Hermit, Royal Arch, and Spring Canyon Creeks). The MRL of 5.0 mg/L was used in the calculations at sample sites that had concentrations where at least one of the fractions was above the MRL.

Most sediment is transported during periods of high water flows and high velocities. Many of the sampled streams had at least one high flow event when visited. These high flow events and the associated increase in suspended sediments can provide a useful estimate of watershed conditions. **Table 14** presents estimated loadings based on watershed area in tons of suspended sediment per unit mile. Previous data has shown the Paria River contributing significant loads to the Colorado River, but two creeks (Tapeats and Shinumo) having less than 90 square miles of watershed area either exceed or equal the load from the Paria River on a square mile basis. The loads were calculated from a single high flow and likely represent a short duration condition.

Turbidity

Turbidity is a measure of how water scatters light and is a gage of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it appears and the greater the turbidity. Turbidity is considered by some investigators to be a good measure of water quality.

Four field turbidity measurements at the Paria River and one at Kanab Creek recorded values above 1000 NTU, which is the upper limit of the turbidity meter. Ten sample sites had turbidity measurements between 10 NTU and 1000 NTU **(Figure 12).** The remaining five sites, not shown, had all four measurements below 10 NTUs. The highest turbidity measurement associated with the highest estimated flow was at Bright Angel Creek (195 cfs), Clear Creek (195 cfs), Shinumo Creek (135 cfs), and Tapeats Creek (720 cfs).

Table 13. Daily Suspended Sediment Concentration loadings at sample sites with and without flood flows.

Site Name	N = 4, All Samples Included			N = 3, Flood Flow Samples Removed		
	Mean Fine Fraction, tons/day	Mean Coarse Fraction, tons/day	Mean Total SSC, tons/day	Mean Fine Fraction, tons/day	Mean Coarse Fraction, tons/day	Mean Total SSC, tons/day
Paria River	872	247	1119	No Flood	No Flood	No Flood
Tapeats Creek	70	95	165	93	0.2	93
Shinumo Creek	21	33	54	0.5	0.5	1
Bright Angel Creek	16	30	46	0.2	0.2	0.4
Kanab Creek	8	15	23	0.5(a)	0.2(a)	0.7
Clear Creek	15	1	16	18	1	19
Havasu Creek	7	5	12	0.05	0.02	0.07
Deer Creek	2	0.2	2	3	0.3	3
Crystal Creek	2	1	3	No Flood	No Flood	No Flood
Nankoweap Creek	1	1	2	1(a)	0.5(a)	1.5
Diamond Creek	0.2	0.1	0.3	0.02	0.02	0.04
Royal Arch Creek	0.01	0.01	0.02	0.005	0.005	0.01
Matkatamiba Creek	0.01	0.01	0.02	No Flood	No Flood	No Flood
Hermit Creek	0.01	0.01	0.02	No Flood	No Flood	No Flood
Three Springs Creek	0.003	0.006	0.009	0.004(a)	0.008(a)	0.012
Spring Canyon Creek	0.003	0.003	0.006	No Flood	No Flood	No Flood
Monument Creek	0.002	0.003	0.005	No Flood	No Flood	No Flood

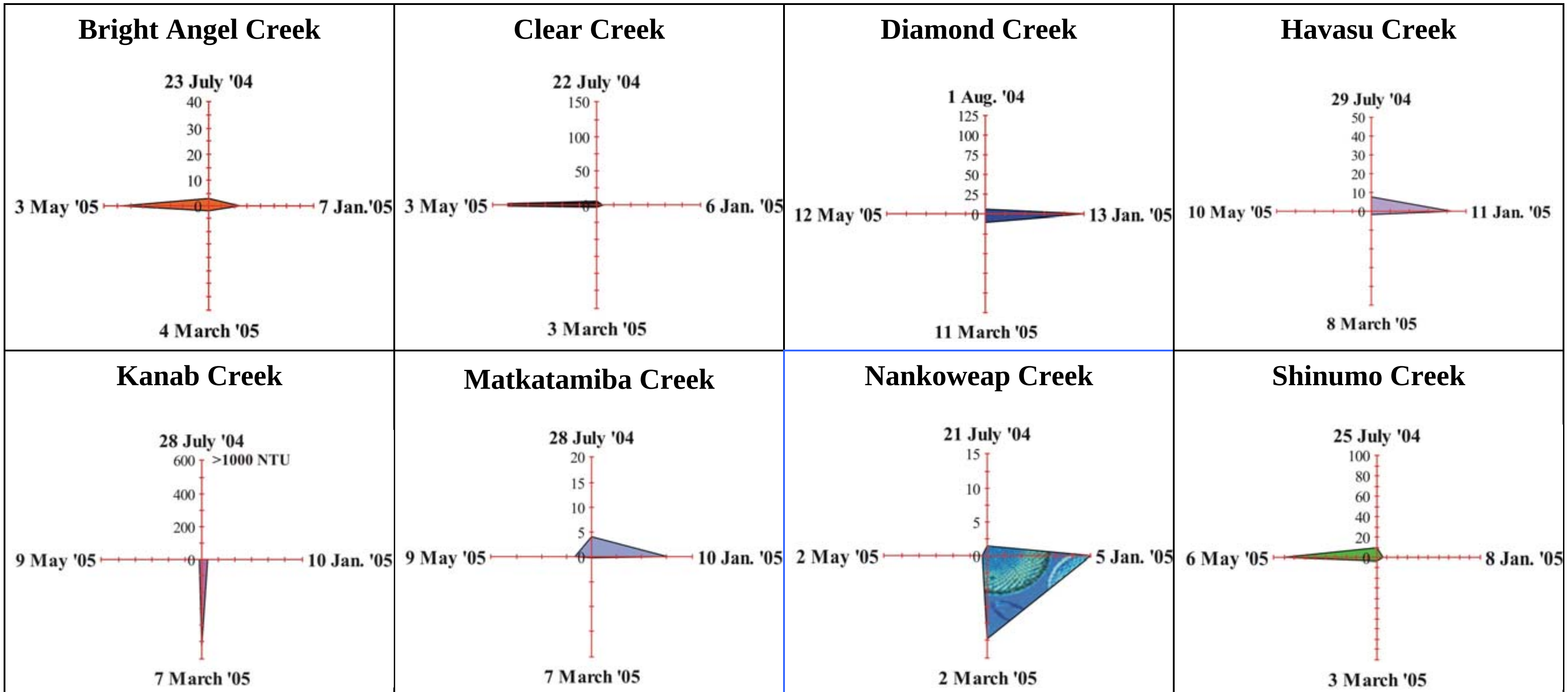
Note:
(a) Site did not have a flood; the low flow was the outlier and omitted from the calculation.
Red highlighted values indicate exceptionally high loadings compared to other sites

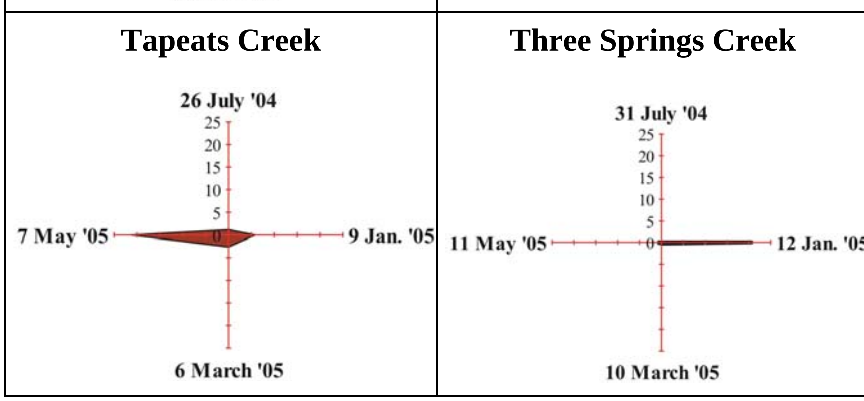
Table 14. Creeks having the highest suspended sediment loadings per square mile of watershed area.

Site	Flow, cfs	SSC, tons/day	Watershed Area, sq. mi.	SSC, tons/sq. mi.
Tapeats Creek[a]	720	213	84	3
Shinumo Creek[a]	135	182	86	2
Paria River	50	2809	1410	2
Clear Creek	47	49	36	1
Bright Angel Creek[a]	195	88	100	1
Deer Creek	23	1	17	0.1

a – An estimated discharge. Stream at time of sampling was in flood

Figure 12. Turbidity as NTU by site and date.





Note:
1. Turbidity at Kanab Creek on 28 July 2004 exceeded 1000 NTU.
2. Missing data point at Spring Canyon Creek and Three Springs Creek on 31 July 2004.
3. Sites having four turbidity measurements less than 10 NTU are not shown.
4. Paria River having four turbidity measurements above 1000 NTU is not shown.

Bacteria

The occurrence of pathogenic microorganisms in water supplies can be a threat to human health. Historically, fecal coliform and total coliform were used as indicator organisms for fecal contamination of water, but these groups included bacteria from non-human sources and could give false positives for human contamination. *Escherichia coli* (*E. coli*) is found in the gastrointestinal tract and feces of all mammals. The recent development of simple plating tests for the detection of *E. coli* bacteria has replaced the formerly used coliform tests.

To process the sample, the subject water is filtered through a 0.45 micron filter, placed on m-TEC media, and incubated at 35 °C for 24 ±2 hours. Upon completion of the incubation period, the bacteria colonies are immediately counted and reported as the number of colony forming units per 100 milliliters of water (cfu/100 ml). If large or small numbers of colonies are present on the filter, a false representation of *E. coli* contamination may result. Valid and statistically reliable counts are from an *ideal colony* count of between 20 and 60 colonies per media plate. Counts from non-ideal conditions, however, are reported with a qualifying notation.

Each state develops water quality standards based upon criteria determined under Section 304 (a) of the Clean Water Act of 1972 and its amendments. In Arizona, the acute water-quality standard for a grab sample of *E. coli* is 235 cfu/100 ml and the chronic standard is 126 cfu/100 ml for the Full Body Contact designated use, which is the most stringent standard of the designated uses for bacteria. The chronic standard is determined from the geometric mean of the last four samples taken at least 24 hours apart. When *E. coli* counts exceed either standard, there is a statistically greater risk of people experiencing gastrointestinal illnesses.

Results

E. coli colonies were rarely found in the sampled tributaries **(Appendix D).** Fifty-eight of the 64 samples yielded counts below 50 cfu/100 ml and the median of all samples was 2 cfu/100 ml. These concentrations would be considered at background non-contaminated levels at other streams throughout the state. Media contamination or processing difficulties from four sample sites in July 2004 did not yield *E. coli* data; the sites were Deer, Kanab, Matkatamiba and Tapeats Creeks. Six of the 64 samples had values of 100 cfu/100 ml or greater **(Table 15).** Three of those exceeded the acute standard. The geometric mean of four Paria River samples is 411 cfu/100 ml, which also exceeds the chronic water quality standard.

Table 15. Bacteria samples exceeding 100 cfu/100 ml.

Sample Site	Date	cfu/100 ml	Qualifier
Bright Angel Creek	4 Mar. 2005	103	
Diamond Creek	1 Aug. 2004	148	
Paria River	26 Apr. 2005	**250**	Non-ideal count
Paria River	31 Jan. 2005	**317**	Non-ideal count
Paria River	08 Nov. 2004	200	Non-ideal count
Paria River	20 Jul. 2004	**1800**	

Note: Red highlighted values indicate an exceedence of the acute *E. coli* water quality standard of 235 cfu/100 ml.

The relationship between flow, *E. coli* colony counts, rain on day of sampling and rain within 24-hours previous to sampling were evaluated. With the exception of Bright Angel Creek, there were no discernable effects of these conditions on *E. coli* populations. Colonies were not observed on the media plate for the January sample which had light rain on sample day, heavy rain the previous day, and moderate flow at day of sampling. It is likely that this sample was taken on the receding hydrograph and the channel had been scoured of some biological life. Flood flows during the May sampling and heavy rain previous to day of sampling appears to have decreased *E. coli* counts when compared to dates without previous rain and with low flow **(Table 16).**

Table 16. Effects of flow and rain on *E. coli* colony counts at Bright Angel Creek.

Date	Rain at time of sampling	Rain within previous 24-hours to sampling	Flow, cfs	*E. coli* colony counts/100 ml
23 July 2004	None	None	16	22 B
7 January 2005	Light	Heavy	35	ND
4 March 2005	None	None	45	103
3 May 2005	None	Heavy	195 J	ND

B – Non-ideal colony count
ND – No colonies observed on media
J – Estimated flow, stream at flood stage

Conclusions

The presence of *E. coli* in Grand Canyon tributaries was minimal and within normal background non-contaminated levels with the exception of the Bright Angel Creek and Paria River. The Paria consistently had high *E. coli* counts during the study period and 75% of the grab samples were not in compliance with the acute water quality standard (235 cfu/100 ml). The chronic standard (126 cfu/100 ml), calculated from four samples taken over a nine month period, was exceeded. Caution and the necessary protective gear should be applied when contacting water at any time of the year from the Paria River.

Study objectives did not address the issue of human impacts on water quality due to recreation (hiking, camping, canyon boat tours) and habitation of permanent residents within the Canyon. The bacteria data presents limited information on this issue which makes it difficult to make definitive statements regarding human impacts and threats to human health. Generally, however, the low *E. coli* counts, in compliance with state water quality standards, appear to present a favorable condition for contact with tributary waters. It is recommended that upstream/downstream bacteria samples be taken in those areas where human usage is high to corroborate these findings.

BIOASSESSMENTS AND HABITAT ASSESSMENTS OF COLORADO RIVER TRIBUTARY STREAMS

Background

While the results from water chemistry analysis have discovered a few significant water quality issues, the biological data presents a different view, but with qualifications. ADEQ's bioassessments utilize in-stream macroinvertebrate data to provide an assessment of the condition of aquatic life. These assessments are made by comparison of study site community data (such as species richness) to a statewide composite reference community using an Index of Biological Integrity for cold or warm water streams. Collection and analysis procedures and a description of the Indexes are provided in ADEQ's "Manual of Procedures for the Sampling of Surface Waters" (Lawson, ed., 2006). These Indexes and the statewide reference condition for macroinvertebrates are the basis for the proposed Narrative Biocriteria Standard in the Draft Surface Water Standards (AAC, 2007). Guidelines for analysis of biological data and use of the biocriteria standard are presented in the "Narrative Biocriteria Standard Implementation Procedures for wadeable, perennial streams" (ADEQ, 2006). While this proposed standard has not been adopted as yet, the data are presented here as supplementary information. The narrative biocriterion reads as follows and the associated numeric targets are shown in **Table 17**.

The Proposed Narrative Biocriterion:

"The biological integrity of a wadeable, perennial stream, as determined by the applicable Arizona Index of Biological Integrity (IBI), shall be protected at or above the 25th percentile of reference condition. An IBI score that is at or above the 25th percentile meets the biocriterion. An IBI score that falls below the 10th percentile of reference condition violates the biocriterion. An IBI score that falls between the 10th and 25th percentile of reference score is determined to be inconclusive and a verification sample is required to determine whether there is a violation. If the verification sample IBI score falls below the 25th percentile, the biocriterion is violated."

Table 17. **Macroinvertebrate Index of Biological Integrity thresholds for wadeable, perennial streams of Arizona.**

Macroinvertebrate bioassessment result	Index of Biological Integrity Score		Assessment category
	Cold water	Warm water	
Greater than the 25th percentile of reference condition	≥ 52	≥ 50	Attaining
Between 10th and 25th percentile of reference	46 – 51	40 – 49	Inconclusive
Less than the 10th percentile of reference condition	≤ 45	≤ 39	Impaired

This report presents the number and percent of stream sites in each assessment category, and a description of the macroinvertebrate community and habitat conditions occurring during the spring 2005 sample event.

Methods and Study Area

During the spring quarterly sampling event (May 2005), ADEQ collected macroinvertebrate samples from 12 different tributary streams to the Colorado River in the Grand Canyon **(Table 18).** Macroinvertebrate samples were not collected from two streams where water chemistry was collected in spring 2005. These north rim streams were still in flood stage in May 2005 due to the large amount of winter snow pack and resulting snowmelt, so Bright Angel Creek and Tapeats Creek were unwadeable and therefore biological samples were not collected. Several other streams were still at elevated flow, but wadeable. Macroinvertebrate samples were collected from all of the wadeable Colorado River tributaries, even if at elevated flows, to supplement our biological inventory. Follow-up samples were collected at low flow during July 2006 on 10 streams. The ten are listed in **Table 18**; however the data were not available at publication time of this report. These data will be presented in an addendum to this report in 2007.

The 2005 macroinvertebrate data are assessed along with an additional 40 historic samples that were collected in July of 1992, 93 and 94 and October of 1997. Samples were collected using Biocriteria Program standard protocols for macroinvertebrate sample collection (Lawson, 2006). Taxonomic identifications **(Appendix E)** of samples taken in 2005 were conducted by Ecoanalysts Inc, an ADEQ contract laboratory. Analysis of the data was conducted by comparison to the ADEQ cold and warm water Indexes of Biological Integrity which are fully described in the ADEQ Biocriteria Quality Assurance Program Plan (2006). The cold water IBI was applied only to Tapeats Creek, due to the cold water spring fed condition of this stream. The warm water IBI was applied to all other sampled tributaries.

The Indexes of Biological Integrity (IBI) were developed for warm water macroinvertebrate communities generally located at elevations <5000 feet above sea level and for cold water communities found at elevations >5000 feet. A statewide network of reference data was used to develop and calibrate the IBIs (Gerritsen and Leppo, 1998; Leppo and Gerritsen, 2000). The IBIs apply to all wadeable, non-effluent dependent, perennial streams located in these regions, with a few exceptions.

The cold and warm water indexes consist of several metrics or key attributes of the benthic macroinvertebrate community which best distinguish impairment from the reference condition. The **cold water IBI** consists of seven metrics selected for their ability to discriminate impairments in cold water streams located at >5000' foot elevation: total taxa richness, Diptera taxa richness, intolerant taxa richness, Hilsenhoff Biotic Index, percent composition by Plecoptera (stoneflies), percent composition by scrapers, and scraper taxa richness. The **warm water IBI** consists of nine metrics which best discern impairment in warm water streams located at <5000 foot elevation: total taxa richness, Ephemeroptera (mayflies) taxa richness, Trichoptera (caddisflies) taxa richness, Diptera taxa richness, percent composition of Ephemeroptera, percent composition by the dominant taxon, Hilsenhoff Biotic Index score, percent composition by scrapers, and scraper taxa richness. The metrics are calculated from a list of species and their abundances and the total IBI score is an average of the metric scores.

Table 18. ADEQ Macroinvertebrate sample collection history at Colorado River tributary stream sites, 1992-2006.

Sample Sites	Site Code	Sampling history					
		June 1992	July 1993	July 1994	Oct. 1997	May 2005	July 2006
Bright Angel Creek	CGBRA000.44	X	X	X	X		
Clear Creek	CGCLE000.19					X	
Crystal Creek	CMCRY000.05		X	X	X	X	X
Deer Creek	CGDEE000.07			X	X	X	X
Diamond Creek	CGDIA000.06					X	
Garden Creek	CGGDN000.82				X		
Havasu Creek	CGHAV001.09	X					
Hermit Creek	CGHRM000.08					X	X
Hermit Creek	CGHRM000.27				X		
Hermit Creek	CGHRM001.58	X	X	X			
Kanab Creek	CGKAN000.26	X	X	X		X	
Matkatamiba	CGMAT000.03	X				X	
Monument Creek	CGMON000.19					X	X
Nankoweap Creek	CGNAN000.20	X	X			X	X
National Creek	CGNAT000.48		X	X	X		X
Paria River	CGPAR001.62	X					
Royal Arch Creek	CGRYA000.05	X	X	X	X	X	X
Shinumo Creek	CGSHN000.11						X
Spring Canyon	CGSPG000.17	X	X	X		X	X
Spring Canyon	CGSPG000.43				X		
Tapeats Creek	CGTAP000.08	X	X	X			
Tapeats Creek	CGTAP000.57				X		X
Three Springs Cyn	CGTHS000.04		X	X	X	X	

Overall Bioassessment Results

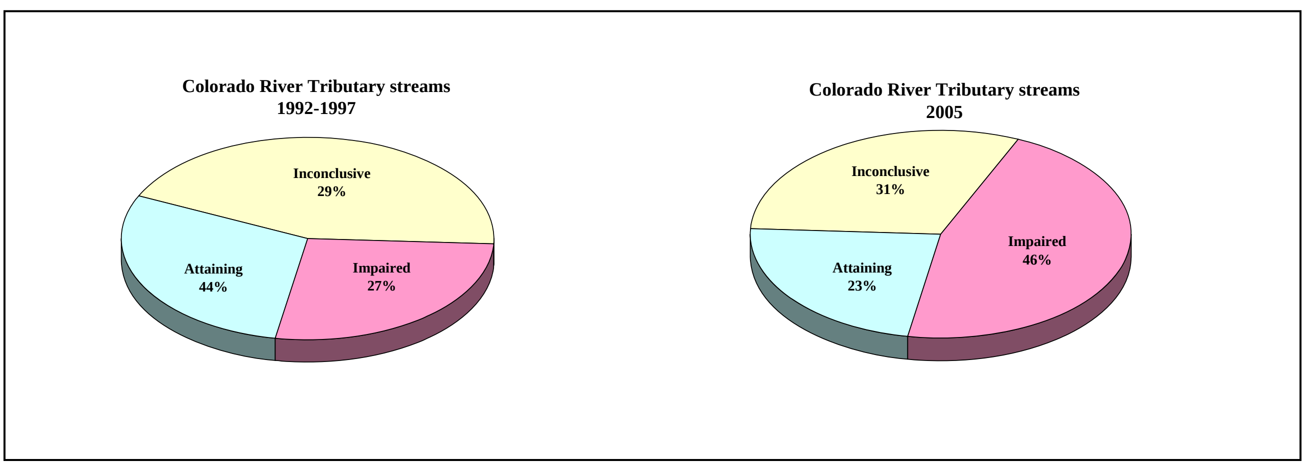
The following results for spring 2005 samples are presented for informational purposes only. The biological samples were "compromised" due to natural flooding conditions. These data cannot be used for 305(b) assessment and 303(d) listing purposes because high floods exclude their use. The terms "attaining, inconclusive, and impaired" are used relative to the Biocriteria assessment categories and do not reflect 305(b)/303(d) assessments.

The majority of bioassessment scores for macroinvertebrate samples collected in May 2005 were impaired or inconclusive, when compared to the ADEQ warm water IBI **(Table 19).** There were 6 samples in the impaired category, 4 inconclusive, and 3 attaining the biocriterion. As a percentage, 46% of the macroinvertebrate samples were in impaired condition. This is a surprisingly high percentage of impaired samples and stream reaches compared to other evaluated streams in the State and considering that there is generally very little human impact in these drainages. This high percentage of 2005 impaired samples is nearly twice the percentage of impaired samples from previous samples collected from 1992-97 (27%) as shown in **Figure 13**. Throughout all sample events from 1992-2005, there were 24 samples (36%) attaining the biocriterion, 19 inconclusive (29%), and 23 impaired (35%). Kanab Creek was the only tributary for which samples attained the biocriterion on all sample events prior to 2005. There were several tributary streams for which all historic samples were impaired: Havasu Creek, Garden Creek, Monument Creek, Nankoweap Creek, Paria River, and Tapeats Creek. Havasu Creek has travertine deposits covering the substrate, a bottom material that is unsuitable for macroinvertebrate colonization. The Paria River has a sand dominated substrate that is unfavorable for insect habitat. Tapeats Creek is a cold water stream, and therefore the macroinvertebrate data has been compared with the cold water IBI; however, more investigation is needed to determine the appropriate reference for this stream.

Table 19. Bioassessment scores for Colorado River tributary streams sampled in May 2005.

Sampling Sites 2005	Stream Aspect (North or South Rim)	Warm Water IBI Score	Assessment Category
Clear Creek	North	36.0	Impaired
Crystal Creek	North	34.7	Impaired
Diamond Creek above road crossing	South	48.3	Inconclusive
Diamond Creek below road crossing	South	51.4	Attaining
Deer Creek	North	41.9	Inconclusive
Hermit Creek	South	51.4	Attaining
Kanab Creek	North	47.1	Inconclusive
Matkatamiba Creek	South	38.5	Impaired
Monument Creek	South	36.3	Impaired
Nankoweap Creek	North	18.6	Impaired
Royal Arch Creek	South	42.3	Inconclusive
Spring Canyon	North	36.5	Impaired
Three Springs Canyon	South	51.5	Attaining

Figure 13. Comparison of 2005 and historic macroinvertebrate IBI Scores.



Analysis of the metric level data reveals more about the status of the macroinvertebrate community in Colorado River tributaries in 2005. Most of the spring 2005 macroinvertebrate metric values did not meet the warm water reference thresholds, as shown in **Table 20.** The total taxa richness metric value averaged 22 taxa in the 2005 dataset; nearly half the warm water - reference threshold value of 37. The number of scraper taxa (algae eaters) and percent composition by scrapers were also notably low at 1.2% for each metric, compared with reference values of 7 and 23.7, respectively **(Table 20).** The percent composition by mayflies was low compared to the reference threshold, with an average metric value of 44% compared with the reference value of 70%. The percent composition by the single most dominant taxon made up a large percentage of the community abundance, with an average metric value of 59% compared with the threshold value of 19%. The importance of the percent mayflies and percent most dominant taxon metrics relative to the other warm water index metrics is shown in **Figure 14**. The most dominant organisms were black flies, midges and Baetidae mayflies, all either filter feeders or collector-gatherers. These organisms are the early colonizers which are multivoltine (producing several broods in a single season) and can feed from the organic particles brought by winter runoff. The multivoltine taxa are most resilient, some completing their life cycle in as little as two weeks (Gray, 1981). The dominance of these fast growing organisms, along with the low diversity or taxa richness is indicative of a benthic community in the early successional stage of development. The lack of scrapers is also indicative of early post-flood conditions, where the algal community is not yet well developed. These factors have resulted in low metric values and low IBI scores for the Colorado River tributary streams sampled in May of 2005.

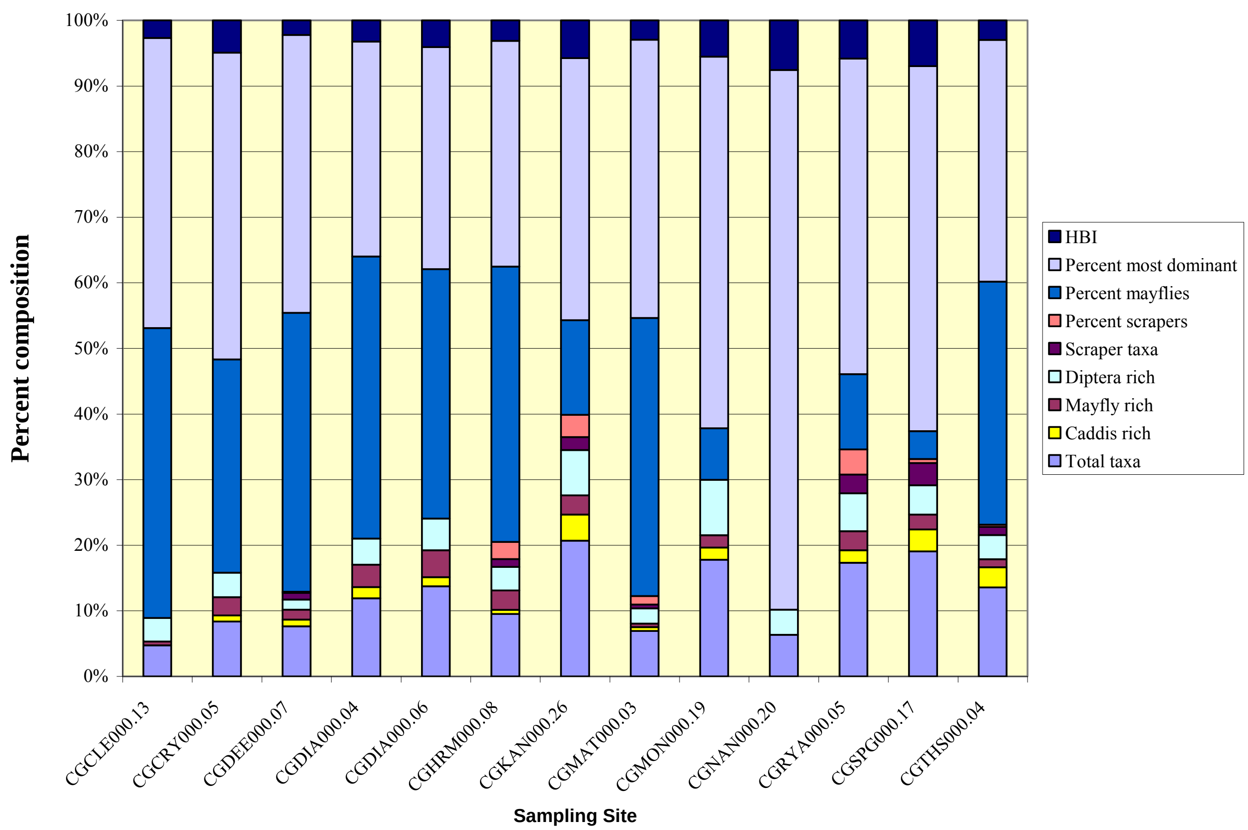


Figure 14. Relative importance of 9 macroinvertebrate metrics in 13 Colorado River tributary sites sampled in May 2005.

Table 20. Warm water macroinvertebrate metric values for Colorado River Tributary streams sampled in May 2005.

Site	Aspect	Total taxa richness	Caddisfly taxa richness	Mayfly taxa richness	Diptera taxa richness	Scraper taxa richness	Percent scrapers	Percent mayflies	Percent most dominant taxon	Hilsenhoff Biotic Index	Most dominant taxon	Functional Feeding Group
Metric Threshold >		**37**	**9**	**9**	**10**	**7**	**23.7**	**70**	**19.1**	**4.89**		
CGCLE000.13	**N**	8	0	1	6	0	0	74.4	74.4	4.51	*Baetis tricaudatus*	Collector-Gatherer
CGCRY000.05	**N**	9	1	3	4	0	0.0	35.0	50.3	5.31	*Simulium*	Filterer
CGDEE000.07	**N**	15	2	3	3	2	0.3	83.4	83.0	4.35	*Baetis tricaudatus*	Collector
CGDIA000.04	**S**	21	3	6	7	0	0.0	75.7	57.6	5.73	*Acentrella insignificans*	Collector
CGDIA000.06	**S**	20	2	6	7	0	0.0	55.3	49.2	5.90	*Acentrella insignificans*	Collector
CGHRM000.08	**S**	16	1	5	6	2	4.3	70.4	57.7	5.21	*Baetis magnus*	
CGKAN000.26	**S**	21	4	3	7	2	3.4	14.6	40.5	5.81	*Simulium*	Filterer
CGMAT000.03	**S**	12	1	1	4	1	2.3	73.4	73.4	5.12	*Baetis magnus*	
CGMON000.19	**S**	19	2	2	9	0	0.0	8.4	60.5	5.91	*Simulium*	Filterer
CGNAN000.20	**N**	5	0	0	3	0	0.0	0.0	64.6	5.93	*Simulium*	Filterer
CGRYA000.05	**S**	18	2	3	6	3	4.0	11.9	50.0	6.02	*Chironomidae*	Collector
CGSPG000.17	**N**	17	3	2	4	3	0.6	3.8	49.6	**6.21**	*Chironomidae*	Collector
CGTHS000.04	**S**	22	5	2	6	2	0.5	60.1	59.8	4.81	*Fallceon quilleri*	Collector

Geographic Analysis of Biological Results

A regression analysis of macroinvertebrate IBI scores with size of the drainage area provided some unexpected results **(Figures 15 and 16).** We would generally predict an inverse correlation between IBI score and drainage area. However we found that there was a slight positive, but insignificant correlation in both the 2005 (R^2=0.15) and 1992-2005 datasets (R^2=0.04). The majority of study sites had drainage areas <100mi^2, with only Kanab Creek and Havasu Creek having large watershed sizes in the 2300-3000mi^2 range. It is difficult to make meaningful inferences when the sample sizes between large and small watersheds are so disproportionate; however, Kanab Creek in 2005 did not have a significantly different warm water IBI score than the smaller Colorado River tributaries. Flood effects may have moderated the watershed effects on the macroinvertebrate community.

Figure 15. Correlation between drainage area and warm water IBI Score, May 2005.

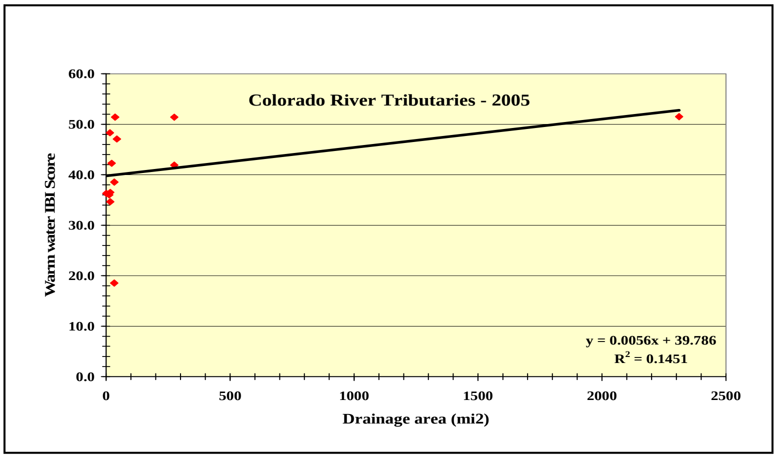
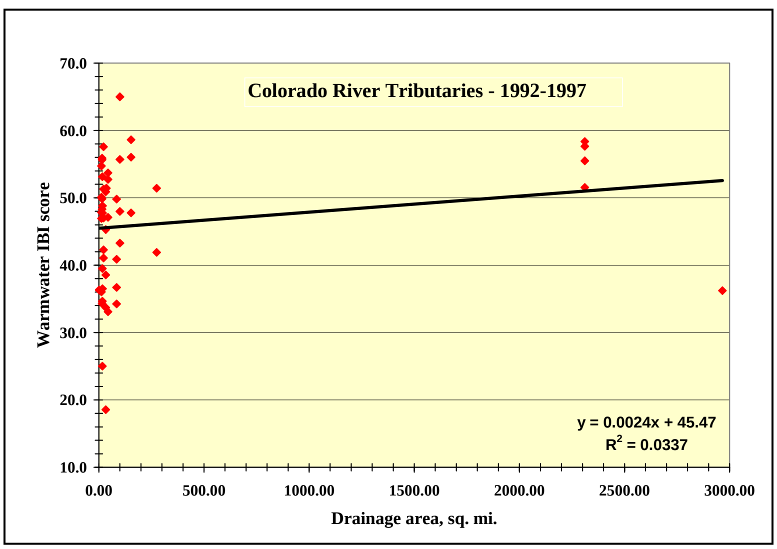


Figure 16. Correlation between drainage area and warm water IBI score, 1992-1997.



North and South Rim Stream Comparisons

There were differences in the composition and species distribution of the macroinvertebrate community (spring 2005) between North and South Rim tributary streams. South Rim stream communities contained nearly twice as many total taxa, mayfly taxa, caddisfly taxa, Diptera taxa, percent scrapers and percent mayflies when compared with North Rim streams. This is likely the result of continued high scouring flows in all the North Rim streams during the May 2005 sample event, from near record snowfall/snowmelt on the North Rim during the previous winter. The overall richness and abundance of macroinvertebrates was greater in South Rim streams because flows were more moderate and the snow pack was significantly less than on the North Rim side.

The species distribution was different between North and South Rim stream communities in spring 2005. *Baetis tricaudatus* was the dominant mayfly at several North Rim streams (Clear, Crystal and Deer Creeks), whereas *Baetis magnus* was the dominant mayfly in South Rim streams (Hermit, Matkatamiba, Monument, and Royal Arches). Other mayfly taxa were the dominant species in other streams. *Baetis notos* was the dominant mayfly in Kanab Creek, *Acentrella insignificans* was dominant in Diamond Creek and *Fallceon quilleri* was common to Spring Creek and Three Springs Creek. There were no mayflies present in Nankoweap Creek. Stoneflies were only found in two streams in spring 2005; *Hesperoperla pacifica* in Deer Creek and Capniidae in Kanab Creek, both North Rim streams. The families of caddisflies represented in the 2005 sample included: Hydropsychidae, Hydroptilidae, Philopotamidae, and Rhyacophilidae. The genera *Hydropsyche* and *Ochrotrichia* were widely distributed throughout North and South Rim streams. Several caddisfly genera were only found in Spring Creek or Three Springs Creek, such as *Chimarra* and *Rhyacophila*.

The biomass of macroinvertebrates in North Rim streams was also much less than the South Rim streams. On average the South Rim macroinvertebrate density, from a $3m^2$ area of stream bottom, was nearly 40% more than in North Rim streams, with the exception of Deer Creek on the North Rim. The macroinvertebrate density in Deer Creek was greater than in any other tributary stream sampled in spring 2005. The constant temperature and flow of this spring-fed stream, which is more insulated from the scouring snowmelt that most other North Rim streams experienced, is likely the reason for higher macroinvertebrate density. Oberlin et al (1999) also found that spring fed tributaries originating within the Grand Canyon had higher macroinvertebrate biomass than tributaries draining large watersheds from outside the Grand Canyon. Spring fed streams maintain a more constant temperature and discharge which is more conducive to algal growth. This growth is of critical importance as a food source and habitat for macroinvertebrates. The streams that originate outside the Grand Canyon and drain large watersheds experience larger and more damaging flow events than the spring fed streams within Grand Canyon. As a result of these high flows, the stream bottom is thoroughly scoured on a seasonal basis. These disturbances reset the benthic community and result in less biomass and diversity of the macroinvertebrate community in the largest tributaries to the Colorado River.

Other Patterns in the Data

Low macroinvertebrate density and diversity are also partly due to physico-chemical factors. Some of the tributary streams with large drainages have water quality characterized by high TDS and $CaCO_3$ with travertine deposits on the stream bottom. These deposits make the stream bottom uninhabitable by bottom dwelling macroinvertebrates and thus limit biological diversity: Havasu Creek and Nankoweap Creek are good examples of this. Other streams with low biomass and diversity are those that are bedrock dominated and have little inhabitable substrate, such as Matkatamiba Creek.

Some patterns became evident when examining the data over a period of years. The greatest IBI scores were obtained from samples collected at numerous Grand Canyon tributaries during the fall of 1997. The lowest IBI scores were generally obtained from spring 2005 samples **(Appendix F).** These findings suggest that the spring index period may not be the ideal sampling period for macroinvertebrates. An alternate sampling period should be considered when re-sampling for macroinvertebrates. The ideal macroinvertebrate sampling period occurs when hydrologic conditions are stable. Therefore, the elevated IBI scores in fall of 1997 suggest that perhaps an October-November fall index period might be the optimum collection period.

A comparative analysis was conducted at two sites on Diamond Creek to evaluate the effects of multiple road crossings along the stream near its terminus. CGDIA000.06 was located upstream of the road crossing and CGDIA000.04 downstream. The IBI scores from the two locations were similar and not significantly different, which was unexpected. Typically, poor habitat and muted biological diversity is found below dirt road crossings.

Habitat Results

Extensive physical habitat data was collected at each of the Colorado River tributary monitoring sites at the time of macroinvertebrate sample collection during Spring 2005. These data included percent filamentous algae cover, macrophyte cover, percent fines (<2mm) in the substrate, embeddedness in riffles, percent canopy density of riparian vegetation over the streambed, riparian vegetation identification, and Proper Functioning Condition category of the riparian area **(Appendix G).** The percent algae cover was generally low among most sites (<1%), with the exception of Spring Canyon Creek where algae cover was >75%. The percent macrophyte cover was also negligible at all sites. The density of macroinvertebrates in Spring Canyon Creek corresponded with the increased algae cover. Primary production is generally greatest in tributaries originating within the Grand Canyon and the periphyton is the most important food source for macroinvertebrates (Oberlin, 1999). The large percent cover of periphyton in Spring Canyon suggests that it was not severely affected by winter flooding due to its small watershed size (22 mi^2) and perhaps the mean elevation of its drainage area.

Substrate conditions were generally good, with a mixture of particle sizes and low embeddedness. Percent fines (<2mm) ranged from 0-16% with a mean of 5.2% and embeddedness ranged from 0-28% with a mean of 20%. These conditions are ideal for macroinvertebrate habitat. Percent fines in this range will meet the proposed ADEQ Surface Water bottom deposits standard of 50%. The overall stream channel habitat was dominated by riffle habitat (94%), with very little pool habitat (2.6%), due to the steep gradient of these canyon channels as they approach the Colorado River. The steep channel gradient and dominant erosional habitat (riffles) of the Colorado River tributaries are key determinants of the hydrology, stream ecology and condition of the benthic community.

Riparian vegetation was minimal in the Colorado River tributary channels during spring 2005, having been recently scoured by the high flows from winter snowmelt. Riparian tree cover on the channel floodplains was generally <20% except for Royal Arch Creek (25%) and Spring Canyon Creek (40%). The dominant riparian community type was cottonwood-willow. A riparian corridor assessment was conducted using the Bureau of Land Management's "Proper Functioning Condition" method. Conditions ranged from "proper functioning" for a Grand Canyon stream (n=4) to "non-functional" (n=2), with several streams classified as "functional at-risk". These riparian assessments are not reliable indicators of normal conditions in Grand Canyon tributary streams, because of the recent scouring winter floods and because these disturbance-prone channels may not meet expectations of other warm-water healthy riparian communities.

Conclusions

A definitive statement on the attainment of the biocriterion cannot be made at this time due to high flow conditions during sampling, the possibility of a more appropriate index period for the Grand Canyon ecosystem, and the need to develop a region-specific reference community for Colorado River tributary streams.

The macroinvertebrate samples collected during May 2005 were affected by continued snowmelt, high flows and the associated scouring of the stream bottom substrate. The majority of these samples appeared "impaired" when compared with the warm and cold water macroinvertebrate community IBIs; however, the flood and post-flood condition of the investigated streams disallows that data from 305(b) and 303(d) assessments. The flows were exceptionally high in May 2005 due to record snow pack on the North Rim. It is common for Colorado River tributaries to be at flood stage into the month of June, which makes sampling during the ADEQ IBI spring index period problematic. Further research is required to determine whether a fall index period is a more stable hydrologic period, and thus a more appropriate time for macroinvertebrate sampling on Grand Canyon tributary streams.

Substrate and channel characteristics limit development of the macroinvertebrate community. When compared to the state biocriterion, 46% of the macroinvertebrate samples were in "impaired" status. This is a high percentage of "impaired" samples for streams which mostly have pristine watersheds, with varying amounts of recreation. Some of the streams have limited habitable substrate, being dominated by either travertine deposits or bedrock. The absence of favorable habitat decreased macroinvertebrate community diversity and biomass. Additionally, the steep channel gradient and dominant erosional habitat of the Colorado River tributaries are key determinants for the hydrology, stream ecology and the condition of the benthic community. These tributary streams are disturbance prone and thus only the moderate to highly tolerant and resilient macroinvertebrate species are present. The most tolerant and ubiquitous taxa were found among all the Colorado River tributaries in 2005 (e.g. black flies, midges and Baetid mayflies), but there were more taxa and biomass present in South Rim streams than North Rim streams, which were still receiving high flow events at time of sampling.

Despite the high flows and low IBI scores present in the spring 2005 samples, there was a high percentage (27%) of "impaired" IBI scores in the historic dataset as well. While there are factors that can be linked to this impairment (i.e. low percent algae and vegetation cover, and low PFC scores), there are few likely human sources of stress on most of the channels. However, the relationship between biological impairment and recreational use of these streams requires further investigation. The stress on these streams appears to be natural and related to the steep channel gradients and a unique hydrology characteristic of Colorado River tributaries. The biological communities of these disturbance prone tributary streams may not achieve the typical macroinvertebrate community structure and function of other warm water streams across the state; therefore, the warm water IBI scoring criteria may not be applicable. Further research is required to either modify the warm water IBI scoring criteria to meet best attainable conditions in these tributary streams or develop a discrete IBI for the unique streams of this region.

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APPENDIX A

Site Codes and Sample Site Locations

ADEQ Site Code	Sample Site and Location	Latitude ddmmss.sss	Longitude Dddmmss.sss
CGBRA000.44	Bright Angel Creek - Below Phantom Ranch	360608.500	1120542.500
CGBRA001.36	Bright Angel Creek - Above Phantom Ranch	360642.500	1120517.500
CGCLE000.19	Clear Creek - Above Colorado River	360502.9	1120200.4
CGCRY000.05	Crystal Creek - Above Colorado River	360807	1121436.500
CGDEE000.07	Deer Creek - Above Colorado River	362321.500	1123027.500
CGDIA000.06	Diamond Creek - Above Mouth at Mile 225.70	354555	1132221
CGHAV000.36	Havasu Creek - Above Colorado River	361815.500	1124529.500
CGHRM000.08	Hermit Creek - Above Colorado River	360555.500	1121231.500
CGKAN000.26	Kanab Creek - Above Colorado River	362339.500	1123754.500
CGMAT000.03	Matkatamiba Creek - Above Colorado River	362037.500	1124017.500
CGMON000.19	Monument Creek - Above Colorado River	360547.1	1121102.5
CGNAN000.20	Nankoweap Creek - 100 Meters Above Colorado River	361818.500	1115135.500
CGPAR001.62	Paria River - Above Colorado River	365221.500	1113600.500
CGRYA000.05	Royal Arch Creek - Above Colorado River	361150.500	1122700.50
CGSHI000.05	Shinumo Creek - Above Colorado River	361414.43	1122052.6
CGSPG000.17	Spring Canyon Creek - Above Colorado River	360107.500	1132109.500
CGTAP000.08	Tapeats Creek - At Colorado River	362215.500	1122803
CGTHS000.04	Three Springs Creek - Above Colorado River	355302.470	1131826.95

APPENDIX B

Arizona Designated Uses of Grand Canyon Sampled Streams

Stream	A&Wc	A&Ww	FBC	DWS	FC	AgL
Bright Angel Creek		X	X		X	
Clear Creek		X	X		X	
Crystal Creek		X	X		X	
Deer Creek		X	X		X	
Diamond Creek	Designated uses not applicable					
Havasu Creek		X	X		X	
Hermit creek		X	X		X	
Kanab Creek		X	X	X	X	X
Matkatamiba Creek		X	X		X	
Monument Creek		X	X		X	
Nankoweap Creek		X	X		X	
Paria river		X	X		X	
Royal Arch Creek		X	X		X	
Shinumo Creek		X	X		X	
Spring Canyon Creek		X	X		X	
Tapeats Creek	X		X		X	
Three Springs Creek	Designated uses not applicable					

A&Wc – Aquatic and Wildlife cold water
A&Ww – Aquatic and Wildlife warm water
FBC – Full Body Contact
DWS – Domestic Water Source
FC – Fish Consumption
AgL – Agricultural Livestock watering

APPENDIX C

Summary and Raw Data Tables of Ultra-Clean Metals Analysis for Copper (Cu), Lead (Pb) and Mercury (Hg)

Bright Angel Creek			
Statistic	Cu, Diss. µg/L	Pb, Diss. µg/L	Hg, Diss. µg/L
Range of values	0.76 - 1.70	0.04 - 0.17	0.0003 - 0.0017
Mean	1.09	0.10	0.0008
Geometric mean	1.03	a	0.0007
Number of samples	4	2	4
Clear Creek			
Range of values	0.31 - 0.71	0.20 - 0.24	0.0002 - 0.0005
Mean	0.49	0.22	0.0004
Geometric mean	0.46	a	a
Number of samples	4	2	3
Crystal Creek			
Range of values	0.63 - 1.78	0.03 - 0.69	0.0005 - 0.0033
Mean	1.16	0.27	0.0012
Geometric mean	1.08	a	a
Number of samples	4	3	3
Deer Creek			
Range of values	0.24 - 0.36	0.05 - 0.05	0.0003 - 0.0011
Mean	0.30	0.05	0.0006
Geometric mean	0.30	a	a
Number of samples	4	1	3
Diamond Creek			
Range of values	0.57 - 0.83	0.45 - 0.45	0.0005 - 0.0007
Mean	0.67	0.45	0.0005
Geometric mean	a	a	a
Number of samples	3	1	3
Havasu Creek			
Range of values	0.24 - 0.43	0.45 - 0.69	0.0003 - 0.0021
Mean	0.33	0.57	0.0009
Geometric mean	0.33	a	a
Number of samples	4	2	3
Hermit Creek			
Range of values	1.87 – 2.99	0.11 – 0.11	0.0003 – 0.0008
Mean	2.25	0.11	0.0005
Geometric mean	2.21	a	0.0005
Number of samples	4	1	4

Kanab Creek			
Statistic	Cu, Diss. µg/L	Pb, Diss. µg/L	Hg, Diss. µg/L
Range of values	1.19 - 2.96	0.02 - 0.11	0.0009 - 0.0043
Mean	2.27	0.06	0.0021
Geometric mean	2.15	a	0.0017
Number of samples	4	3	4
Matkatamiba Creek			
Range of values	1.87 - 2.99	0.11 - 0.11	0.0003 - 0.0008
Mean	2.25	0.11	0.0005
Geometric mean	2.21	a	0.0005
Number of samples	4	1	4
Monument Creek			
Range of values	0.35 - 2.74	0.12 - 0.77	0.0002 - 0.0127
Mean	1.75	0.45	0.0044
Geometric mean	1.33	a	a
Number of samples	4	2	3
Nankoweap Creek			
Range of values	0.44 - 1.84	0.02 - 0.13	0.0005 - 0.0006
Mean	0.99	0.08	0.0005
Geometric mean	0.83	a	a
Number of samples	4	2	2
Paria River			
Range of values	3.02 - 3.18	0.10 - 0.27	0.0032 - 0.0049
Mean	3.10	0.18	0.0040
Geometric mean	a	a	a
Number of samples	2	2	3
Royal Arch Creek			
Range of values	0.76 - 1.70	0.04 - 0.17	0.0003 - 0.0017
Mean	1.09	0.10	0.0008
Geometric mean	1.03	a	0.0007
Number of samples	4	2	4
Shinumo Creek			
Range of values	0.17 - 0.85	0.14 - 0.18	0.0005 - 0.0011
Mean	0.43	0.16	0.0008
Geometric mean	0.36	a	a
Number of samples	4	2	3

Spring Canyon Creek			
Statistic	Cu, Diss. µg/L	Pb, Diss. µg/L	Hg, Diss. µg/L
Range of values	0.47 - 1.19	0.03 - 0.38	0.0010 - 0.0010
Mean	0.78	0.20	0.0010
Geometric mean	0.72	a	a
Number of samples	4	2	3
Tapeats Creek			
Range of values	0.16 - 0.40	0.04 - 0.04	0.0004 - 0.0011
Mean	0.28	0.04	0.0008
Geometric mean	0.26	a	a
Number of samples	4	1	2
Three Springs Creek			
Range of values	0.43 - 1.47	0.02 - 0.44	0.0003 - 0.0006
Mean	0.83	0.16	0.0004
Geometric mean	0.75	a	0.0004
Number of samples	4	3	4

a – The number of samples does not meet the four sample criterion to determine the chronic standard. Either the bottle was damaged at the contract laboratory or the result was below the Method Detection Limit (MRL).

Raw Data from Sample Sites

BRIGHT ANGEL CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGBRA000.44	05/03/05	0.489	0.110	3.66
CGBRA000.44	03/04/05	0.587	ND	0.657
CGBRA000.44	01/07/05	0.231	0.0223	0.349
CGBRA000.44	07/23/04	0.240	ND	ND
CGBRA001.36	05/04/05	0.503	0.165	NA

CGBRA000.44 = Bright Angel Creek below Phantom Ranch
CGBRA001.36 = Bright Angel Creek above Phantom Ranch
NA = Not Analyzed (sample bottle damaged at analyzing laboratory)
ND = Non-Detect; analytical results were below the Method Reporting Limit

To determine whether the Phantom Ranch facilities were contributing trace metals to Bright Angel Creek a single sample, upstream of the ranch, was collected (4 May 2005) 1.36 miles above the confluence with the Colorado River and 0.92 miles above the downstream sampling point. The following table shows those results.

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGBRA000.44	05/03/05	0.489	0.110	3.66
CGBRA001.36	05/04/05	0.503	0.165	NA

The above ranch sample showed copper having a simple difference of 2.8% from the sample collected below the ranch. Lead results from above and below had a difference of 33.3%. The above ranch mercury sample bottle was damaged at the contract laboratory and data is not available.

CLEAR CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGCLE000.19	05/03/05	0.712	0.244	NA
CGCLE000.19	03/03/05	0.554	ND	0.542
CGCLE000.19	01/06/05	0.378	0.197	0.322
CGCLE000.19	07/22/04	0.310	ND	0.220

Field blanks were processed on 01/06/2005. Results were below the MRL for the three parameters.
Field duplicates collected and processed on March 3, 2005:
Copper = 0.553 µg/L; relative percent difference from grab sample = 0.2%
Lead = Non-detect
Mercury = 0.728 ng/L; relative percent difference = 29%

CRYSTAL CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGCRY000.05	05/05/05	0.633	0.0882	3.34
CGCRY000.05	03/05/05	1.78	ND	0.566
CGCRY000.05	01/08/05	1.24	0.694	0.54
CGCRY000.05	07/24/04	0.97	0.03	0.49

Field blanks and field duplicates were not collected at this site.

DEER CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGDEE000.07	05/07/05	0.355	0.0465	1.11
CGDEE000.07	03/07/05	0.315	ND	0.317
CGDEE000.07	01/09/05	0.304	ND	0.469
CGDEE000.07	07/26/04	0.24	ND	ND

NA = Not Available; flood event, not sampled for dissolved copper, lead and mercury
Field blanks were processed on 05/07/2005. Results were below the MRL for the three parameters.

DIAMOND CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGDIA000.37	05/12/05	NA	NA	NA
CGDIA000.06	03/11/05	0.831	ND	0.467
CGDIA000.06	01/13/05	0.567	0.449	0.506
CGDIA000.06	08/01/04	0.60	ND	0.67

Field blanks were processed on 03/11/2005. Results were below the MRL for the three parameters.

HAVASU CREEK

Site is located adjacent to the USGS gauge station located in Havasu Canyon

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGHAV000.36	05/10/05	0.336	0.692	0.284
CGHAV000.36	03/08/05	0.425	ND	2.080
CGHAV000.36	01/11/05	0.240	0.449	ND
CGHAV000.36	07/29/04	0.330	ND	0.380

Field blanks were processed on 03/08/2005. Results were below the MRL for the three parameters.
Field duplicates collected and processed on January 11, 2005:
Copper = 0.262 µg/L; relative percent difference from grab sample = 8.8%
Lead = 0.450 µg/L; relative percent difference from grab sample = 0.2%
Mercury = 0.448 ng/L; field blank was a non-detect (< 0.20)
Field duplicates collected and processed on July 29, 2004:
Copper = 0.30 µg/L; relative percent difference from grab sample = 8.9%
Lead = ND; field grab also ND (<0.020)
Mercury = 0.40 ng/L; relative percent difference from grab sample = 5.3%

HERMIT CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGHRM000.08	05/05/05	0.622	0.0737	0.257
CGHRM000.08	03/05/05	1.460	ND	0.495
CGHRM000.08	01/07/05	0.658	0.575	0.376
CGHRM000.08	07/24/04	0.710	ND	0.320

Field blanks were processed on 03/08/2005. Results were below the MRL for all three parameters.

KANAB CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGKAN000.26	05/09/05	2.68	0.0235	0.94
CGKAN000.26	03/07/05	2.96	ND	0.978
CGKAN000.26	01/10/05	1.19	0.113	2.03
CGKAN000.26	07/28/04	2.26	0.041	4.31

Field blanks and field duplicates were not collected at this site.

MATKATAMIBA CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGMAT000.03	05/09/05	1.87	ND	0.534
CGMAT000.03	03/07/05	2.99	ND	0.809
CGMAT000.03	01/10/05	2.13	0.109	0.274
CGMAT000.03	07/28/04	2.02	ND	0.37

Field blanks were processed on 07/28/2004. Results were below the MRL for the three parameters.
Field duplicates collected and processed on May 9, 2005:
Copper = 1.84 µg/L; relative percent difference from grab sample = 1.6%
Lead = ND; field grab results also reported as ND
Mercury = 0.393 ng/L; relative percent difference from grab sample = 30%

MONUMENT CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGMON000.19	05/05/05	2.71	0.119	0.262
CGMON000.19	03/04/05	2.74	ND	12.7
CGMON000.19	01/07/05	1.19	0.771	0.212
CGMON000.19	07/24/04	0.35	ND	ND

Field blanks were processed on 05/05/2005. Results were below the MRL for the three parameters.

Field sheet notes from 03/04/05 indicate recent surface related activity in the general area of the monitoring point; there was evidence of invasive exotic plant removal, specifically salt cedar. Evidence of chain-saw cuts and fresh debris piles seemed to suggest that the activity had occurred prior to the site visit, but is unknown whether this ground disturbance is related to the high mercury concentration.

NANKOWEAP CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGNAN000.20	05/02/05	0.524	0.02	NA
CGNAN000.20	03/02/05	1.14	ND	0.551
CGNAN000.20	01/05/05	1.84	0.132	0.477
CGNAN000.20	07/21/04	0.44	ND	ND

Field blanks were not collected at this site.
Field duplicates collected and processed on January 5, 2005:
Copper = 1.64 µg/L; relative percent difference from grab sample = 11%
Lead = 0.0692 µg/L; relative percent difference from grab sample = 62%
Mercury = 0.967 ng/L; relative percent difference from grab sample = 68%
Field duplicates collected and processed on March 2, 2005:
Copper = 1.09 µg/L; relative percent difference from grab sample = 4.5%
Lead = ND; field grab also ND (<0.020 µg/L)
Mercury = ND; field grab results = 0.551 ng/L

PARIA RIVER

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGPAR001.62	04/26/05	NS	NS	NS
CGPAR001.62	01/31/05	3.02	0.097	4.88
CGPAR001.62	11/04/04	NS	NS	NS
CGPAR001.62	07/20/04	3.18	0.265	3.18

NS = Not Sampled; unable to process due to high turbidity levels (> 1000 NTU)
Field blanks were processed on 07/20/2004. Results were below the MRL for the three parameters.
Field duplicates collected and processed on January 31, 2005:
Copper = 3.33 µg/L; relative percent difference from grab sample = 9.8%
Lead = 0.088 µg/L; relative percent difference from grab sample = 9.7%
Mercury = 2.9 ng/L; relative percent difference from grab sample = 51%

The samples for the Paria River site were not collected on the same sampling schedule as the Grand Canyon tributary samples. The site was sampled under the Ambient Monitoring Program.

ROYAL ARCH CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGRYA000.05	05/06/05	0.949	0.0425	0.567
CGRYA000.05	03/06/05	1.7	ND	0.735
CGRYA000.05	01/08/05	0.932	0.166	1.67
CGRYA000.05	07/25/04	0.76	ND	0.27

Field blanks and field duplicates were not collected at this site.

SHINUMO CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGSHI000.05	05/06/05	0.434	0.179	NA
CGSHI000.05	03/03/05	0.849	ND	1.1
CGSHI000.05	01/08/05	0.265	0.144	0.454
CGSHI000.05	07/25/04	0.17	ND	ND

Field blanks were processed on 07/25/2004. Results were below the MRL for the three parameters.
Field blanks were processed on 05/06/2005. Results were below the MRL for copper and lead.
The mercury field blank bottle was damaged at the contract laboratory and data is not available.

SPRING CANYON CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGSPG000.17	05/11/05	0.469	ND	ND
CGSPG000.17	03/10/05	0.942	ND	ND
CGSPG000.17	01/12/05	1.19	0.38	1.01
CGSPG000.17	07/31/04	0.52	0.027	ND

Field blanks were processed on 03/10/2005. Results were below the MRL for the three parameters.

TAPEATS CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGTAP000.08	05/07/05	0.376	0.0393	NA
CGTAP000.08	03/06/05	0.4	ND	0.446
CGTAP000.08	01/09/05	0.202	ND	1.11
CGTAP000.08	07/26/04	0.16	ND	ND

Field blanks and field duplicates were not collected at this site.

THREE SPRINGS CREEK

Site I D	Date	Cu (D) µg/L	Pb (D) µg/L	Hg (D) ng/L
CGTHS000.04	05/11/05	0.685	0.0242	0.427
CGTHS000.04	03/10/05	1.47	ND	0.62
CGTHS000.04	01/12/05	0.731	0.436	0.306
CGTHS000.04	07/31/04	0.43	0.028	0.42

Field blanks were processed on 07/31/2004. Results were below the MRL for the three parameters.
Field blanks were processed on 03/10/2005. Results were below the MRL for the three parameters.
Field duplicates collected and processed on May 11, 2005:
Copper = 0.717 µg/L; relative percent difference from grab sample = 4.6%
Mercury = 0.403 ng/L; relative percent difference from grab sample = 5.8%

APPENDIX D

E. coli Occurrence by Site and Date

Stream Name and Location	Sample Dates and *E. coli* colony counts/100 ml				
BRIGHT ANGEL CREEK - BELOW PHANTOM RANCH	23-JUL-2004	07-JAN-2005	04-MAR-2005	04-MAY-2005	03-MAY-2005
	22 B	ND : 1	103	ND : 1	ND : 1
CLEAR CREEK - ABOVE COLORADO RIVER	22-JUL-2004	06-JAN-2005	03-MAR-2005	03-MAY-2005	
	4 B	ND : 1	ND : 1	ND : 1	
CRYSTAL CREEK - ABOVE COLORADO RIVER	24-JUL-2004	08-JAN-2005	05-MAR-2005	05-MAY-2005	
	6	ND : 1	2 B	4 B	
DEER CREEK - ABOVE COLORADO RIVER	26-JUL-2004	09-JAN-2005	07-MAR-2005	07-MAY-2005	
	46a	ND : 1	2 B	1 B	
DIAMOND CREEK - ABOVE MOUTH AT 225.70	01-AUG-2004	13-JAN-2005	11-MAR-2005	12-MAY-2005	
	148 A	ND : 1	17 B	1 B	
HAVASU CREEK - ABOVE COLORADO RIVER	29-JUL-2004	11-JAN-2005	08-MAR-2005	10-MAY-2005	
	19 B	2	6 B	4 B	
HERMIT CREEK - ABOVE COLORADO RIVER	24-JUL-2004	07-JAN-2005	05-MAR-2005	05-MAY-2005	
	4 B	ND : 1	1 B	2 B	
KANAB CREEK - ABOVE COLORADO RIVER	28-JUL-2004	10-JAN-2005	07-MAR-2005	09-MAY-2005	
	a	2	27 B	9 B	
MATKATAMIBA CREEK - ABOVE COLORADO RIVER	28-JUL-2004	10-JAN-2005	07-MAR-2005	09-MAY-2005	
		ND : 1	2 B	4 B	
MONUMENT CREEK - ABOVE COLORADO RIVER	24-JUL-2004	07-JAN-2005	04-MAR-2005	05-MAY-2005	
	17 B	ND : 1	2 B	1 B	

Continued from Previous Page				
NANKOWEAP CREEK - 100 METERS ABOVE COLORADO RIVER	21-JUL-2004	05-JAN-2005	02-MAR-2005	02-MAY-2005
	ND : 2	4 B	ND : 1	ND : 1
PARIA RIVER - ABOVE COLORADO RIVER	20-JUL-2004	08-NOV-2004	31-JAN-2005	26-APR-2005
	1800	200 B	317 B	250 B
ROYAL ARCH CREEK - ABOVE COLORADO RIVER	25-JUL-2004	08-JAN-2005	06-MAR-2005	06-MAY-2005
	ND : 2	ND : 1	2 B	ND : 1
SHINUMO CREEK - ABOVE COLORADO RIVER	25-JUL-2004	08-JAN-2005	06-MAR-2005	06-MAY-2005
	ND : 2	ND : 1	2 B	ND : 1
SPRING CANYON CREEK - ABOVE COLORADO RIVER	31-JUL-2004	12-JAN-2005	10-MAR-2005	11-MAY-2005
	42	ND : 1	4 B	4 B
TAPEATS CREEK - AT COLORADO RIVER	31-JUL-2004	12-JAN-2005	10-MAR-2005	11-MAY-2005
	42	ND : 1	4 B	4 B
THREE SPRINGS CREEK - ABOVE COLORADO RIVER	31-JUL-2004	12-JAN-2005	10-MAR-2005	11-MAY-2005
	31 B	ND : 1	ND : 1	4 B

ND – No colonies observed on media
a – Count not valid due to contamination of equipment and technique blanks

APPENDIX E

Macroinvertebrate Taxa Collected from 12 Grand Canyon Tributaries

Stream Name:	CLEAR CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGCLE000.13		
Collection Date:	05/03/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis tricaudatus	144	160
Diptera-Chironomidae	Chironomidae	765	32
Diptera	Ceratopogonidae	699	1
	Dicranota sp.	751	2
	Dolichopodidae	1149	1
	Erioptera sp.	752	1
	Simulium sp.	738	16
Acari	Acari	126	2
Taxa Richness	**8**	**Total**	**215**

Stream Name:	CRYSTAL CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGCRY000.05		
Collection Date:	05/05/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis magnus	3533	2
	Baetis tricaudatus	144	183
	Fallceon quilleri	1307	9
Diptera-Chironomidae	Chironomidae	765	70
Diptera	Muscidae	716	2
	Simulium sp.	738	279
	Wiedemannia sp.	714	8
Trichoptera	Rhyacophila coloradensis gr.	667	1
Lepidoptera	Lepidoptera	690	1
Taxa Richness	**9**	**Total**	**555**

Stream Name:	DEER CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGDEE000.07		
Collection Date:	05/07/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetidae	129	1
	Baetis tricaudatus	144	475
	Fallceon quilleri	1307	1
Plecoptera	Hesperoperla pacifica	375	1
Coleoptera	Elmidae	436	1
Diptera-Chironomidae	Chironomidae	765	22
Diptera	Simulium sp.	738	51
	Wiedemannia sp.	714	4
Trichoptera	Hydropsyche sp.	565	6
	Rhyacophila coloradensis gr.	667	1
Gastropoda	Physidae	92	1
Annelida	Oligochaeta	4	4
Acari	Acari	126	2
Crustacea	Ostracoda	121	1
Other Organisms	Turbellaria	2	1
Taxa Richness	**15**	**Total**	**572**

Stream Name:	DIAMOND CRK ABV ROAD CROSSING		
Station ID:	CGDIA000.06		
Collection Date:	05/12/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Acentrella insignificans	131	273
	Baetis adonis	3534	3
	Baetis magnus	3533	7
	Baetis notos	1207	12
	Fallceon quilleri	1307	10
	Tricorythodes sp.	264	2
Odonata	Argia sp.	272	1
	Libellulidae	284	1
Hemiptera	Abedus sp.	1676	1
Megaloptera	Corydalus sp.	1373	1
Diptera-Chironomidae	Chironomidae	765	85
Diptera	Bezzia/Palpomyia sp.	3034	4
	Dixa sp.	706	1
	Muscidae	716	3
	Simulium sp.	738	134
	Stratiomyidae	740	4
	Tipulidae	749	1
Trichoptera	Hydroptila sp.	573	1
	Ochrotrichia sp.	578	1
Acari	Acari	126	10
Taxa Richness	**20**	**Total**	**555**

Stream Name:	DIAMOND CRK BLW ROAD CROSSING		
Station ID:	CGDIA000.04		
Collection Date:	05/12/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Acentrella insignificans	131	303
	Baetis adonis	3534	2
	Baetis magnus	3533	9
	Baetis notos	1207	38
	Fallceon quilleri	1307	41
	Tricorythodes sp.	264	5
Odonata	Argia sp.	272	1
Diptera-Chironomidae	Chironomidae	765	40
Diptera	Ceratopogonidae	699	1
	Dolichopodidae	1149	1
	Empididae	709	1
	Simulium sp.	738	53
	Stratiomyidae	740	1
	Tipulidae	749	1
Trichoptera	Hydroptila sp.	573	1
	Ochrotrichia sp.	578	6
	Rhyacophila coloradensis gr.	667	1
Annelida	Oligochaeta	4	1
Acari	Acari	126	7
Crustacea	Ostracoda	121	2
Other Organisms	Turbellaria	2	11
Taxa Richness	**21**	**Total**	**526**

Stream Name:	HERMIT CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGHRM000.08		
Collection Date:	05/05/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis magnus	3533	292
	Baetis notos	1207	12
	Baetis tricaudatus	144	21
	Baetodes sp.	1456	11
	Fallceon quilleri	1307	20
Coleoptera	Huleechius sp.	1920	1
	Microcylloepus sp.	455	11
Diptera-Chironomidae	Chironomidae	765	55
Diptera	Dixa sp.	706	1
	Hemerodromia sp.	712	2
	Simulium sp.	738	37
	Tabanidae	743	1
	Wiedemannia sp.	714	7
Trichoptera	Hydropsyche sp.	565	9
Acari	Acari	126	24
Other Organisms	Turbellaria	2	2
Taxa Richness	**16**	**Total**	**506**

Stream Name:	KANAB CRK ABV COLORADO RV CONFLUENCE
Station ID:	CGKAN000.26
Collection Date:	05/09/05

Order/Level	Taxon	Taxon Code	Count
Ephemeroptera	Baetis notos	1207	58
	Callibaetis sp.	146	1
	Fallceon quilleri	1307	1
Plecoptera	Capniidae	308	3
Coleoptera	Microcylloepus sp.	455	2
	Postelichus sp.	1905	2
Megaloptera	Corydalus sp.	1373	2
Diptera-Chironomidae	Chironomidae	765	81
Diptera	Bezzia/Palpomyia sp.	3034	5
	Ceratopogonidae	699	1
	Empididae	709	1
	Psychodidae	720	1
	Simulium sp.	738	166
	Wiedemannia sp.	714	2
Trichoptera	Hydropsyche sp.	565	1
	Neotrichia sp.	577	12
	Ochrotrichia sp.	578	45
	Rhyacophila coloradensis gr.	667	1
Annelida	Oligochaeta	4	5
Acari	Acari	126	19
Crustacea	Ostracoda	121	1
Taxa Richness	**21**	**Total**	**410**

Stream Name:	MATKATAMIBA CRK ABV COLORADO RV CONFLU..
Station ID:	CGMAT000.03
Collection Date:	05/09/05

Order/Level	Taxon	Taxon Code	Count
Ephemeroptera	Baetis magnus	3533	387
Odonata	Argia sp.	272	3
Coleoptera	Hydroporinae	2465	1
Megaloptera	Corydalus sp.	1373	1
Diptera-Chironomidae	Chironomidae	765	12
Diptera	Ceratopogonidae	699	1
	Muscidae	716	1
	Simulium sp.	738	100
Trichoptera	Hydropsyche sp.	565	1
Gastropoda	Potamopyrgus antipodarum	1043	12
Acari	Acari	126	6
Other Organisms	Turbellaria	2	2
Taxa Richness	**12**	**Total**	**527**

Stream Name:	MONUMENT CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGMON000.19		
Collection Date:	05/05/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis magnus	3533	43
	Fallceon quilleri	1307	4
Odonata	Argia sp.	272	2
Coleoptera	Agabus sp.	430	11
	Sanfillipodytes sp.	3313	1
Diptera-Chironomidae	Chironomidae	765	102
Diptera	Atrichopogon sp.	1963	2
	Bezzia/Palpomyia sp.	3034	1
	Dixa sp.	706	5
	Euparyphus sp.	742	23
	Hemerodromia sp.	712	8
	Muscidae	716	3
	Simulium sp.	738	338
	Wiedemannia sp.	714	4
Trichoptera	Hydropsyche sp.	565	1
	Ochrotrichia sp.	578	1
Annelida	Oligochaeta	4	2
Acari	Acari	126	4
Other Organisms	Turbellaria	2	4
Taxa Richness	**19**	**Total**	**559**

Stream Name:	NANKOWEAP CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGNAN000.20		
Collection Date:	05/02/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Diptera-Chironomidae	Chironomidae	765	31
Diptera	Bezzia/Palpomyia sp.	3034	1
	Simulium sp.	738	62
Lepidoptera	Lepidoptera	690	1
Acari	Acari	126	1
Taxa Richness	**5**	**Total**	**96**

Stream Name:	ROYAL ARCH CRK ABV COLORADO RV CONFLUE		
Station ID:	CGRYA000.05		
Collection Date:	05/06/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis magnus	3533	52
	Baetodes arizonensis	3310	10
	Fallceon quilleri	1307	1
Odonata	Argia sp.	272	3
Coleoptera	Microcylloepus sp.	455	17
Diptera-Chironomidae	Chironomidae	765	265
Diptera	Bezzia/Palpomyia sp.	3034	1
	Hemerodromia sp.	712	1
	Muscidae	716	1
	Simulium sp.	738	99
	Wiedemannia sp.	714	11
Trichoptera	Hydropsychidae	542	1
	Ochrotrichia sp.	578	9
Gastropoda	Physa (Physella) sp.	94	1
	Potamopyrgus antipodarum	1043	3
Annelida	Oligochaeta	4	44
Acari	Acari	126	4
Other Organisms	Turbellaria	2	7
Taxa Richness	**18**	**Total**	**530**

Stream Name:	SPRING CRK ABV COLORADO RV CONFLUENCE		
Station ID:	CGSPG000.17		
Collection Date:	05/11/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis sp.	145	2
	Fallceon quilleri	1307	18
Odonata	Argia sp.	272	3
Hemiptera	Naucoridae	306	1
Coleoptera	Elmidae	436	1
	Heterelmis sp.	1919	1
	Laccobius sp.	493	1
Diptera-Chironomidae	Chironomidae	765	263
Diptera	Dasyhelea sp.	1962	1
	Neoplasta sp.	2014	1
	Simulium sp.	738	39
Trichoptera	Chimarra sp.	637	7
	Hydroptila sp.	573	180
	Ochrotrichia sp.	578	1
Gastropoda	Physa (Physella) sp.	94	1
Acari	Acari	126	3
Other Organisms	Turbellaria	2	7
Taxa Richness	17	Total	530

Stream Name:	THREE SPRINGS CRK ABV COLORADO RV CONF..		
Station ID:	CGTHS000.04		
Collection Date:	05/11/05		
Order/Level	**Taxon**	**Taxon Code**	**Count**
Ephemeroptera	Baetis magnus	3533	2
	Fallceon quilleri	1307	327
Odonata	Anisoptera	2825	1
	Argia sp.	272	6
Coleoptera	Agabus sp.	430	2
Diptera-Chironomidae	Chironomidae	765	17
Diptera	Bezzia/Palpomyia sp.	3034	1
	Dasyhelea sp.	1962	1
	Dolichopodidae	1149	2
	Simulium sp.	738	163
	Stratiomyidae	740	1
Trichoptera	Chimarra sp.	637	1
	Hydroptila sp.	573	1
	Leucotrichia sp.	575	2
	Ochrotrichia sp.	578	10
	Rhyacophila sp.	678	1
Lepidoptera	Petrophila sp.	692	1
Annelida	Oligochaeta	4	1
Acari	Acari	126	2
Crustacea	Crangonyx sp.	2436	1
Other Organisms	Nematoda	67	1
	Prostoma sp.	2659	3
Taxa Richness	**22**	**Total**	**547**

APPENDIX F

Macroinvertebrate Metric and Index of Biological Integrity Scores for ADEQ/NPS Samples Collected 1992-2006

Site ID	Collection Date	Total Taxa	Diptera Taxa	HBI	Scraper Percent	Scraper Taxa Richness	Caddisfly taxa	Mayfly taxa	Mayflies percent	Dominant Taxon percent	Warm-water IBI score	Assessment category
CGBRA000.44	6/14/1992	14	2	5.7	28.7	5	4	1	29.0	26.4	55.7	Attaining
CGBRA000.44	6/30/1993	16	4	4.9	7.1	2	2	3	57.1	56.3	48.0	Inconclusive
CGBRA000.44	7/4/1994	22	4	5.8	38.8	5	8	2	23.9	30.6	65.0	Attaining
CGBRA001.36	10/14/1997	11	3	5.0	4.9	2	2	2	52.8	49.1	43.3	Inconclusive
CGCLE000.13	5/5/2005	8	6	4.5	0.0	0	0	1	74.4	74.4	51.4	Attaining
CGCRY000.05	7/1/1993	16	5	4.7	5.7	3	3	3	68.2	59.4	52.7	Attaining
CGCRY000.05	7/4/1994	20	6	6.4	20.5	3	5	1	9.0	27.7	53.7	Attaining
CGCRY000.41	10/16/1997	10	3	5.6	0.0	0	3	1	21.4	35.7	33.1	Impaired
CGCRY000.05	5/5/2005	9	4	5.3	0.0	0	1	3	35.0	50.3	47.1	Inconclusive
CGDEE000.07	7/7/1994	18	4	5.7	1.9	3	3	4	23.1	22.5	47.8	Inconclusive
CGDEE000.07	10/20/1997	16	3	5.0	2.5	4	4	2	51.8	51.7	48.8	Inconclusive
CGDEE000.07	5/5/2005	15	3	4.4	0.3	2	2	3	83.4	83.0	36.5	Impaired
CGDIA	5/5/2005	21	7	5.7	0.0	0	3	6	75.7	57.6	41.9	Inconclusive
CGDIA000.06	5/5/2005	20	7	5.9	0.0	0	2	6	55.3	49.2	51.4	Attaining
CGGDN001.09	10/13/1997	16	4	6.2	1.1	1	1	2	2.1	37.9	32.1	Impaired
CGHAV000.36	6/18/1992	10	3	4.5	0.2	1	2	1	83.5	83.5	36.2	Impaired
CGHRM001.58	6/14/1992	22	6	6.7	7.3	2	6	1	15.6	29.2	47.8	Inconclusive
CGHRM001.58	7/1/1993	17	6	5.6	6.0	3	4	1	50.9	50.2	50.1	Attaining
CGHRM001.58	7/4/1994	21	7	7.2	6.9	3	5	1	6.3	24.9	46.9	Inconclusive
CGHRM000.27	10/15/1997	20	8	4.9	4.6	3	2	3	60.3	56.0	54.7	Attaining
CGHRM000.08	5/5/2005	16	6	5.2	4.3	2	1	5	70.4	57.7	36.0	Impaired
CGKAN000.26	6/17/1992		5	5.6	25.1	3	4	1	36.6	35.5	57.7	Attaining
CGKAN000.26	7/4/1993	20	6	4.6	6.5	5	3	2	75.6	74.8	55.5	Attaining
CGKAN000.26	7/8/1994	18	5	5.8	21.5	4	5	1	31.4	31.4	58.3	Attaining
CGKAN000.26	5/5/2005	21	7	5.8	3.4	2	4	3	14.6	40.5	51.5	Attaining
CGMAT000.03	6/18/1992	18	8	5.1	6.4	2	2	2	46.4	45.2	50.9	Attaining
CGMAT000.03	5/5/2005	12	4	5.1	2.3	1	1	1	73.4	73.4	38.5	Impaired
CGMON000.19	5/5/2005	19	9	5.9	0.0	0	2	2	8.4	60.5	36.3	Impaired
CGNAN000.20	6/9/1992	12	5	5.7	9.8	2	2	1	33.6	27.8	45.3	Inconclusive

Site ID	Collection Date	Total Taxa	Diptera Taxa	HBI	Scraper Percent	Scraper Taxa Richness	Caddisfly taxa	Mayfly taxa	Mayflies percent	Dominant Taxon percent	Warmwater IBI score	Assessment category
CGNAT000.48	7/5/1993	15	5	4.8	3.6	2	3	2	74.3	67.5	47.8	Inconclusive
CGNAN000.20	6/29/1993	9	3	5.6	0.8	2	2	2	22.6	56.1	33.7	Impaired
CGNAN000.20	5/5/2005	5	3	5.9	0.0	0	0	0	0.0	64.6	18.6	Impaired
CGNAT000.48	7/9/1994	17	4	5.6	21.7	2	3	3	64.0	37.4	58.6	Attaining
CGNAT000.48	10/21/1997	24	8	5.5	1.6	3	4	4	26.9	24.3	56.0	Attaining
CGPAR001.62	6/7/1992	3	1	6.5	0.0	0	1	1	14.3	83.3	16.5	Impaired
CGRYA000.05	6/15/1992	21	8	6.3	11.2	4	3	1	8.9	37.3	49.8	Attaining
CGRYA000.05	7/2/1993	24	9	6.4	9.2	4	5	3	12.1	39.6	55.9	Attaining
CGRYA000.05	7/5/1994	21	5	7.6	3.6	4	4	1	0.4	78.7	34.3	Impaired
CGRYA000.05	10/17/1997	26	7	5.2	1.2	1	6	4	45.8	43.0	55.6	Attaining
CGRYA000.05	5/5/2005	18	6	6.0	4.0	3	2	3	11.9	50.0	48.3	Inconclusive
CGSPG000.17	6/20/1992	21	6	7.0	1.8	3	4	1	9.3	39.4	41.1	Inconclusive
CGSPG000.17	7/6/1993	24	6	5.9	12.5	3	6	2	28.0	27.9	57.6	Attaining
CGSPG000.17	7/10/1994	22	9	6.4	7.9	3	4	1	10.2	53.8	47.0	Inconclusive
CGSPG000.43	10/23/1997	24	9	6.1	4.3	3	4	5	1.9	46.1	51.3	Attaining
CGSPG000.17	5/5/2005	17	4	6.2	0.6	3	3	2	3.8	49.6	42.3	Inconclusive
CGTAP000.08	6/16/1992	19	6	5.1	2.7	2	4	2	35.5	33.5	36.7*	Impaired
CGTAP000.08	7/3/1993	14	4	5.1	3.3	3	4	2	31.7	34.0	34.3*	Impaired
CGTAP000.08	7/6/1994	18	5	5.0	15.2	2	4	3	38.0	35.0	40.9*	Impaired
CGTAP000.57	10/19/1997	29	8	5.4	20.9	4	7	3	20.3	24.6	49.8*	Impaired
CGTHS000.04	7/6/1993	23	7	6.6	0.2	1	5	2	10.9	60.7	39.5	Inconclusive
CGTHS000.04	7/10/1994	14	4	7.0	0.2	1	4	1	0.2	85.2	25.0	Impaired
CGTHS000.04	10/24/1997	28	9	6.7	5.5	3	5	2	7.6	24.5	53.1	Attaining
CGTHS000.04	5/5/2005	22	6	4.8	0.5	2	5	2	60.1	59.8	34.7	Impaired

* Coldwater IBI Score

APPENDIX G

Sample Site Habitat Assessment Data

Station ID	CGCLE000.19	CGCRY000.05	CGDEE000.07	CGDIA000.06
Collection Date	5/3/2005	5/5/2005	5/7/2005	5/12/2005
Parameter name				
Discharge (ft3/s)	46.82	22.34	23.23	4.57
Recent flood Evidence	1	2	1	1
Precipitation current	none	none	none	none
Precipitation_previous24hr	moderate	none	moderate	none
General appearance stream	1	1	1	1
General appearance banks	1	1	1	1
Water appearance/clarity	2	3	2	1
Water odor	1	1	1	1
Appearance waters edge/salt crusts	1	1	1	3
Fish abundance	1	1	1	3
Crayfish abundance	1	1	1	1
Sunfish	1	1	1	1
Leopard frogs - number alive	0	0	0	0
Leopard frogs - number dead	0	0	0	0
Flow regime	P	P	P	P
Source Water	3	1, 3	3	3
Organic Debris	1	1	2	2
Macroinvert_riffle_field split	0	0	0	0
Percent Filamentous Algae	1	1	1	1
Percent Floating Algae	1	1	1	1
Macrophyte abundance	1	1	1	1
Algae ID				
Aquatic plants ID				
NonPoint_Source_Comments		8700, 8720	8700	8700
Fines_percent_<2mm	0	2	8	2
Particle size, 15th percentile	28	21	8	12
Particle size, 50th percentile	63	49	29	26
Particle size, 85th percentile	110	140	80	50
Size_classes_number	438	13	11	11
Embeddedness_riffles_100count	0	14.4	17.3	25.4
Pool_%	0			0
Riffle_%	100			100
Riffle_Geometry Length-width_ratio	20			2.6
Depositional Features	3	9	4	2
Percent Canopy Density	0	0.5	44	0
Riffle_habitat_quality	3	2	3	2.5
Extent_riffle_habitat	4	4	4	4
Embeddedness_category_2001	4	4	4	3.5
Sediment_deposition_reach	3	4	3	3
Bank_stability	2.5	4	4	3

Continued From Previous Page

Riparian_Veg_Cover_Canopy	0	10		0
Riparian_Veg_Cover_Understory	15	50		10
Riparian_Veg_Cover_Groundcover	10	20		25
Riparian_Veg_Cover_Bare_soil	30	20		75
Riparian_Association	1	1	1	1
Riparian vegetation ID	Seep willow	Coyote Willow, Tamarisk, Seep willow, Cattail, Phragmites	Coyote willow, tamarisk, Seep willow, rushes, equisetum	Tamarisk, mesquite, seep willow
Regeneration Potenial of Rip. Trees	4	1	1	2
PFC	NF	PFC	PFC	NF

Station ID	CGHRM000.08	CGKAN000.26	CGMAT000.03
Collection Date	5/5/2005	5/9/2005	5/9/2005
Parameter name			
Discharge (ft3/s)	1.23	33.42	0.60(e)
Recent flood Evidence	2	1	1
Precipitation_current	None	none	none
Precipitation_previous24hr	None	none	none
General appearance stream	1	1	1
General appearance banks	1	1	1
Water appearance/clarity	1	3	1
Water odor	1	1	1
Appearance waters edge/salt crusts	1	1	1
Fish abundance	1	3	2
Crayfish abundance	1		1
Sunfish	1		1
Leopard frogs - number alive	0		0
Leopard frogs - number dead	0		0
Flow regime	P	P	2
Source Water	1,3	3	3
Organic Debris	2	2	1
Macroinvert_riffle_field split	0	0	0
Percent Filamentous Algae	1	1	1
Percent Floating Algae	1	1	1
Diatom Cover	2	1	2
Macrophyte_abund	1	1	1
Algae ID	Cladophora	Cladophora	Cladophora
NonPoint_Source_Comments	8700, 8720	1000 3100 3200 4000 4600 7400 7550 7700 8700 8730 6300 6500	8700
Fines_percent_<2mm	7	6.8	3
Particle size, 15th percentile	5.7	7	6
Particle size, 50th percentile	24	27	64
Particle size, 85th percentile	65	140	110
Size_classes_number	12	12	10
Embeddedness_riffles_100count	13.8	27.9	16.7
Pool_%	5	0	
Riffle_%	95	100	
Riffle_Geometry Length-width_ratio	4.75	4.1	6
Depositional Features	9	2	4
Percent Canopy Density	20.5	32	24
Riffle_habitat_quality	2	2	2
Extent_riffle_habitat	4	4	4
Embeddedness_category_2001	4	3	4
Sediment_deposition_reach	4	3	2
Bank_stability	3.5	3.5	4
Riparian_Veg_Cover_Canopy	1	15	0
Riparian_Veg_Cover_Understory	75	75	0
Riparian_Veg_Cover_Groundcover	10	25	0
Riparian_Veg_Cover_Bare_soil	25	20	100

Continued From Previous Page

Riparian_Association	1	1	1
Riparian vegetation ID	Coyote willow, Tamarisk, Seep Willow	Mesquite Tamarisk Seep Willow Cattail Phragmites Coyote Willow	Redbud
Regeneration Potenial of Rip. Trees	2	2	3
PFC	PFC	FAR-U	unknown

Station ID	CGMON000.19	CGNAN000.20	CGRYA000.05
Collection Date	5/5/2005	5/2/2005	5/6/2005
Parameter name			
Discharge (ft3/s)	0.268	20.3	0.42
Recent flood Evidence	2	2	3
Precipitation_current	NONE	none	LIGHT
Precipitation_previous24hr	NONE	light	HEAVY+HAIL
General appearance stream	1	1	1
General appearance banks	1	1	1
Water appearance/clarity	1	1	1
Water odor	1	1	1
Appearance waters edge/salt crusts	1	1	1
Fish abundance	1	1	2
Crayfish abundance	1	1	1
Sunfish	1	1	1
Leopard frogs - number alive	2(red ear?)	0	1
Leopard frogs - number dead	0	0	1
Flow regime	p	P	p
Source Water	3	3	3
Organic Debris	2	1	2
Macroinvert_riffle_field split	0	1	0
Percent Filamentous Algae	2	1	2
Percent Floating Algae	1	1	1
Diatom Cover	2	1	3
Macrophyte_abund	1	1	1
Algae ID	Cladophora		Blue-green, stoneworts
Aquatic plants ID			Monkey flower
NonPoint_Source_Comments	8700, 8720		8700, 8720
Fines_percent_<2mm	15.8	4	4.9
Particle size, 15th percentile	1.6	11	6
Particle size, 50th percentile	14	27	57
Particle size, 85th percentile	55	60	150
Size_classes_number	12	12	11
Embeddedness_riffles_100count	24	24	27
Pool_%	4	0	
Riffle_%	96	100	
Riffle_Geometry Length-width_ratio	6.28	10	40
Depositional Features	9	3	9
Percent Canopy Density	6.5	0	32
Riffle_habitat_quality	2	2	3
Extent_riffle_habitat	4	4	4
Embeddedness_category_2001	4	4	3
Sediment_deposition_reach		4	4
Bank_stability	3	4	4
Riparian_Veg_Cover_Canopy	1	0	25
Riparian_Veg_Cover_Understory	30	0	70
Riparian_Veg_Cover_Groundcover	5	0	50
Riparian_Veg_Cover_Bare_soil	64	100	20

Continued From Previous Page

Riparian_Association	1	1	1
Riparian vegetation ID	Cottonwood, Willow, Mesquite, Tamarisk, Baccharus	Tamarisk, Willow	Coyote Willow, Seep Willow, Cattail, Redbud,
Regeneration Potenial of Rip. Trees	2	2	2
PFC	FAR-U	NF	PFC

Station ID	CGSPG000.17	CGTAP000.08	CGTHS000.04
Collection Date	5/11/2006	5/7/2005	5/11/2005
Parameter name			
Discharge (ft3/s)	0.52	720(E)	1.26
Recent flood Evidence	1	7	1
Precipitation_current	none	NONE	NONE
Precipitation_previous24hr	light	MODERATE	NONE
General appearance stream	1	1	1
General appearance banks	1	1	1
Water appearance/clarity	1	3	1
Water odor	1	1	1
Appearance waters edge/salt crusts	1	1	1
Fish abundance	2		1
Crayfish abundance	1		1
Sunfish	1		1
Leopard frogs - number alive	100+	0	0
Leopard frogs - number dead	0	0	0
Flow regime	P	P	P
Source Water	1,3	1,3	3
Organic Debris	2		1
Macroinvert_riffle_field split	0	0	0
Percent Filamentous Algae	5		1
Percent Floating Algae	1		1
Diatom Cover	3		2
Macrophyte_abund	1		1
Algae ID	Spirogyra		Spirogyra
Aquatic plants ID			
NonPoint_Source_Comments	8700	8700 8720	8700
Fines_percent_<2mm	3		5.6
Particle size, 15th percentile	11		7.3
Particle size, 50th percentile	42		13
Particle size, 85th percentile	120		15
Size_classes_number	11		11
Embeddedness_riffles_100count	24.4		24
Pool_%	9		
Riffle_%	62		100
Riffle_Geometry Length-width_ratio	5.5		0.014
Depositional Features	3		3
Percent Canopy Density	26	25	2
Riffle_habitat_quality	4		3
Extent_riffle_habitat	4		4
Embeddedness_category_2001	4		4
Sediment_deposition_reach	3		3
Bank_stability	2		4
Riparian_Veg_Cover_Canopy	40	10	0
Riparian_Veg_Cover_Understory	75	90	7
Riparian_Veg_Cover_Groundcover	30	90	5
Riparian_Veg_Cover_Bare_soil	20	5	90

Continued From Previous page

Riparian_Association	1	1	1
Riparian vegetation ID	Mesquite Tamarisk Seep Willow	Alder, Ash, Mesquite, Tamarisk Coyote Willow, Seep Willow, Equisetum	Phragmites(pseudo)
Regeneration Potenial of Rip. Trees	2	2	4
PFC	FAR-NA		N/A

Station ID	Collection Date	PFC Remarks	Field notes
CGCLE000.19	5/3/2005	Practically no riparian, washed out by recent floods and continued heavy winter runoff	Practically no riparian, washed out by recent floods and continued heavy winter runoff, rocks still actively rolling in watercourse
CGCRY000.05	5/5/2005	proper functioning for this high gradient desert stream	This stream drains the north rim and is experiencing high flows due to extensive snowmelt from 12' snowpack on rim. Lots of petrophila seen
CGDEE000.07	5/7/2005		Stream flow elevated, but not at flood stage like Tapeats, probably due to smaller watershed size
CGDIA000.06	5/12/2005	3-slightly entrenched with excess sediment in channel, 4-channel heavily scoured by winter floods but veg is re-establishing. Few large woody trees, mostly tamarisk with 1 seep willow. Many mid-channel bars were evident. 6-Three classes present for tamarisk, but only large class mesquite and seep willow. 7-Only tamarisk plus 1 seep willow. Cottonwoods were preset up-canyon and should be here. 9 - Obviously riparian vegetation has recently been scoured out. Tamarisk will be removed in a high flow event. 11 - Very little cover <10% for the reach. 12 - Not enough veg to be labeled adequate woody veg. 13-Some boulders, roughness, and minimal veg form a rough channel, but not enough to prevent scouring at bankfull. 14 - Potential for reveg on pseudo point bars but not much occurring so soon post flood. 16 - Relatively stable vertically, but about 1 foot downcut with last floods. 17 - Mid channel bars, downcut with last floods but excess sediment now moving thru channel.	Stream is B4 channel on cobble-gravel alluvial wash; loosely confined within broad canyon. Flows are 3-4" deep x 6' wide, fast riffle - continuous - no pools or runs. Sample location is abv last road crossing. Substrate slightly cemented by travertine/salt deposits, which gives buff color to substrate. No visible filamentous algae; black flies and mayflies are tiny; probably early successional stage. Stream is on Hualapai land-need to share data. Cobble-gravel streambed. Void of vegetation in streambed. Little, mostly tamarisk along stream banks. Tamarisk is dominant riparian veg in this reach, but coverage on banks is sparse at <10%. Only 1 seep willow seen probably most of veg was scoured out during monsoon 2004 and winter floods when Diamond Cr road was washed out.

CGHRM000.08	5/5/2005	No cottonwoods, some downcutting, Tamarisk in 3 age classes but coyote willow only two, prob. Due to scouring winter flows.	Small amount of travertine formation around cobbles, adult damselflies common.
CGKAN000.26	5/9/2005	Mid-channel bars and side bars indicates excess sediment good vegetation at bankfull	Wet clay on floodplain, channel recently flashed to bankfull. Sample reach is in straight section D/S of bend in river with a large point bar. Good mix of gravel, cobble and boulder. Thin layer of silt overlaying the substrate. Joe said flannelmouth suckers and other native fish are in the creek. Beach was shut down to protect fishery. Significant day use at the stream though.
CGMAT000.03	5/9/2005		Site is 200ft U/S of confluence, slot canyon with vertical walls.
CGMON000.19	5/5/2005		Stream has recently flashed due to rain event/winter runoff. Channel damp to bankfull and damp seep willow, some woody debris in channel. Scour from has occurred in channel from flood event. Tadpoles evident in backwater pools and adult mating frogs, many blackflies little else. camping area D/S on beach.
CGNAN000.20	5/2/2005	#2-No riparian vegetation after flood; #13 plenty of rocks but straight channel; #16 could be downcutting; #17 excessive erosion	Large debris fan from winter flood. Habitat devastated. Travertine nailing everything down. Very low habitat diversity. Riparian taken out; no understory or overstory.
CGRYA000.05	5/6/2005		Cascade pool system with productive riffles. Good vegetation- abundance of plants, tadpoles seen in pools. Popular hiking spot, poor camp area at beach.

CGSPG000.17	5/11/2006	Prevalent seep willow and tamarisk no coyote willow.	Very little recreation use at this site due to lack of camping areas. Well vegetated banks line B type channel. Abundance of algae and overall production is highest of any trib stream sampled in last six years. Tremendous amount of juvenile frogs, three species-red, white, black. The banks are cut 2-3 ft high on both sides due to high flows. The stream has recovered quite well from scour that occurred last year. There were three different species of butterflies observed.
CGTAP000.08	5/7/2005		Stream at flood stage during visit, not wadeable, streamflow estimated. Sampling activities limited due to high flows.
CGTHS000.04	5/11/2005	A type channel-bedrock with no vegetation.	Three springs canyon scoured in August 2004 from heavy monsoon rains. Just a few patches of vegetation remain. The channel is contained by bedrock and is now filling with gravel/sand cobbles substrate that has created a fast riffle habitat. Diatoms and unicellular greens give streambed a yellow-green color. The stream is still recovering from a high flow event in march but has recovered enough to produce good algae, but insects are still in early successional stage, very small mayflies. No beach for camping, occasional day hikers.

Definitions of Variables in Appendix G	
Recent flood Evidence	Categories 1=None, 2=Fresh debris line in channel abv bankfull elev, 3=grasses laid over, 4=Fresh debris line in bushes/trees, 5=other, 6=drought conditions prevailing, 7=recent flood event greater than baseflow but less than bankfull, 8=Riparian veg scoured away
Precipitation_current	text: none, light, moderate, heavy
Precipitation_previous24hr	text: none, light, moderate, heavy
General appearance stream	Categories 1=no refuse, 2=small amount refuse visible, 3=small amount refuse common, 4=large volume refuse (tires/carts) rare, 5=large volume refuse common
General appearance banks	Categories 1=no refuse, 2=small amount refuse visible, 3=small amount refuse common, 4=large volume refuse (tires/carts) rare, 5=large volume refuse common
Water appearance/clarity	Categories 1=clear, 2=milky, 3=light brown, 4=dark brown, 5=oily sheen, 6=greenish, 7=other
Water odor	Categories 1=none, 2=sewage, 3=chlorine, 4=fishy, 5=rotten eggs, 6=other
Appearance waters edge/salt crusts	Categories 1=No evidence salt crusts, 2=salt crusts rare, 3=salt crusts numerous, 4=banks covered with salt crusts
Fish abundance	Categories 1=absent, 2=rare, 3=common
Crayfish abundance	Categories 1=absent, 2=rare, 3=common
Sunfish	Categories 1=absent, 2=rare, 3=common
Leopard frogs - number alive	number field
Leopard frogs - number dead	number field
Flow regime	string field
Source Water	Categories 1=Snowmelt runoff, 2=stormflow runoff, 3=spring fed, 4=regulated flows, 5=altered flows due to urban streams, clear cuts ect
Organic Debris	Categories 1=No organic debris, 2=infrequent debris, 3=Moderate debris <10%, 4=Numerous debris piles <30%, 5=Debris dams in 30-50% of channel area, 6=Extensive/continuous debris >50% channel, 7=Beaver dams infrequent, 8=Beaver dams frequent with backwater between dams, 9=Beaver dams with channel adjustments, 10=Human structures obstructing channel
Macroinvert_riffle_field split	number 0-1
Percent Filamentous Algae	categories 1=<1%, 2=1-25%, 3=26--50%, 4=51-75%, 5=76-100%
Percent Floating Algae	categories 1=<1%, 2=1-25%, 3=26--50%, 4=51-75%, 5=76-100%
Diatom Cover	categories 1=absent, 2=thin coating, 3=thick coating
Macrophyte_abund	categories 1=<1%, 2=1-25%, 3=26--50%, 4=51-75%, 5=76-100%
Non-point source comments	enter code
Fines_percent_<2mm	number field 0-100
Particle size, 15th percentile	number field 0-100
Particle size, 50th percentile	number field 0-100
Particle size, 85th percentile	number field 0-100
Size_classes_number	number field 0-16
Embeddedness_riffles_100count	number field 0-100
Pool %	number
Riffle %	number
Riffle_Geometry Length-width_ratio	number field 0-100
Depositional Features	Categories 1=Point bars, 2=point bars with few mid-channel bars, 3=numerous mid-channel bars, 4=side bars, 5=diagonal bars, 6=main channel branching with numerous mid-bars and islands, 7=side bars and mid-channel bars with length exceeding 2-3X channel width, 8=Delta bars, 9=No bars present
Percent Canopy Density	number field 0-100
Riffle_habitat_quality	Habitat Index Categories 1=Poor, 2=marginal, 3=suboptimal, 4=optimal

Continued From Page Above

Extent_riffle_habitat	Habitat Index Categories 1=Poor, 2=marginal, 3=suboptimal, 4=optimal
Embeddedness_category_2001	Habitat Index Categories 1=Poor, 2=marginal, 3=suboptimal, 4=optimal
Sediment_deposition_reach	Habitat Index Categories 1=Poor, 2=marginal, 3=suboptimal, 4=optimal
Bank_stability	Habitat Index Categories 1=Poor, 2=marginal, 3=suboptimal, 4=optimal
Riparian_Veg_Cover_Canopy	number field 0-100
Riparian_Veg_Cover_Understory	number field 0-100
Riparian_Veg_Cover_Groundcover	number field 0-100
Riparian_Veg_Cover_Bare_soil	number field 0-100
Riparian_Association	Categories 1=Sonoran riparian deciduous forest, 2=Interior riparian deciduous forest, 3=montane riparian deciduous forest, 4=arctic boreal forest
Riparian Species	Enter Species Name
Regeneration Potenial of Rip. Trees	Score 1-4
PFC	string field; values=PFC near PNC, PFC, FAR-U, FAR-NA, FAR-D, NF, Unknown